chapter

3 The Cycling of Matter in the Biosphere

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Ecosystems are always changing. Trees in a forest die and are replaced by new trees. Lakes change greatly in temperature and oxygen levels throughout the year. Grasslands are burned by wildfires, and new plants appear. By changing constantly, ecosystems can remain stable, in a dynamic equilibrium, or balance.

The rusting truck in **Figure 1**, on the next page, reminds us of some of the ways that ecosystems respond to change. In time, the weeds growing around the truck will be replaced by shrubs, and the small trees will grow tall. Pieces of the truck will fall off and be buried under detritus. Eventually, even the iron atoms in the truck will return to the soil.

Where will the atoms and molecules of the truck go? Recall that the biosphere is a closed system. Energy can pass into and out of the biosphere but, other than small amounts in meteorites, matter neither enters nor leaves the biosphere. Instead, all the atoms that make up matter in the biosphere are transformed from one form to another through different cycles. The cycling of matter helps to maintain the environmental conditions that support the organisms in that ecosystem. Any large changes may cause an irreversible shift in the dynamic equilibrium, and a new balance must be established. If changes are too large or too fast, some species may not survive.

STARTING Points

Answer these questions as best you can with your current knowledge. Then, using the concepts and skills you have learned, you will revise your answers at the end of the chapter.

1. One truck abandoned in a forest probably won't affect the ecosystem too much. However, humans produce far more than one waste truck every year. Estimate the number of trucks and cars that are abandoned each year in Canada. What problems might be caused by this volume of waste?
2. Western thought often describes humans as being at the centre of change. In this worldview, the ideal human acts as a protector for an ecosystem. By contrast, Aboriginal peoples describe humans as belonging to an ecosystem, living in harmony with it. How would a description of a grassland ecosystem written by a typical scientist differ from a description written by an Aboriginal elder?
3. Low oxygen levels in landfills limit the number of bacteria that can decompose foods.
   (a) Explain why slow rates of decomposition are a concern.
   (b) Why is reducing wastes so important?

Figure 1
If left here, this truck will slowly disappear, leaving little behind.

Exploration Recycling Matter

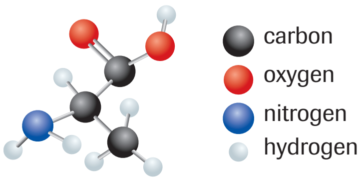
Materials: scissors, shoe box, masking tape, soil, magnifying lens, plastic (e.g., garbage bag), spoon, rubber gloves, beaker, items for testing (newspaper, orange peel, aluminum foil, plastic bottle cap, coffee grounds, lettuce, metal tab from pop can)

- Line a shoe box with plastic from a garbage bag. Tape the plastic along the top edge of the box.
- Place about 8 cm of soil in the shoe box and add enough water to make the soil moist. Arrange different items for testing on the surface of the soil. Cover each item with a layer of moist soil.
- Place the shoe box in a warm, sunny place for the next month. Keep the soil moist by adding water when needed.
- Examine each item once a week. Each time, put on rubber gloves and use a spoon to remove the top layer of soil. Put the soil in a beaker. Examine each sample using a hand lens. Cover the materials with the soil after you examine them.

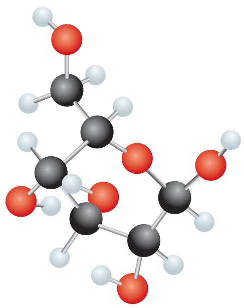
(a) Explain why you lined the box with plastic.
(b) Record your observations in a chart.
(c) Why should you wear rubber gloves to examine the materials?

3.1 The Hydrological Cycle

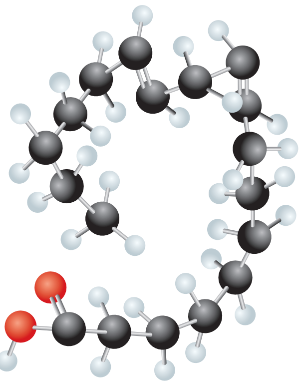
To understand how matter cycles through ecosystems, we must also understand the cycling of organic substances within living things. Living organisms contain many organic compounds, which are substances that contain atoms of carbon and hydrogen. Proteins, sugars, and fats, the important chemicals that make up your body, are all organic (**Figure 1**). Organic compounds undergo changes within living things and within ecosystems. Their complex structures are broken and rebuilt in a continuous cycling of matter.



(a) alanine, an amino acid. Amino acids are used to build proteins, which regulate the chemistry of the cell and make up most of its structures.



(b) glucose, a sugar. Sugars are used to store energy.



(c) linoleic acid, a fatty acid. Fatty acids are combined to form fats, which are used to store energy and to build cell membranes.

Figure 1
Three organic molecules. Note that they all contain carbon and hydrogen atoms. Some organic molecules are extremely complex. A DNA molecule, for example, contains millions of atoms.

Cycling of Organic Matter

The materials used in building the bodies of living organisms are limited to the atoms and molecules that make up the planet. There is no alternative source of matter. Therefore, to maintain life on Earth, matter must be recycled.

Incredible as it may sound, every carbon atom is recycled time and time again into new life forms. Because of this cycling, it is possible that somewhere in your body are atoms that once made up a *Tyrannosaurus rex*, one of the giant carnivorous dinosaurs that lived 70 million years ago.

Food is organic matter. Every time you eat, organic matter that was once part of other living things passes into your body. Through the process of digestion, complex organic molecules are broken down into simpler molecules. Cells use these simple molecules to build the complex molecules that become part of your own structure.

Another process involved in the cycling of matter is decay. Organic materials are held temporarily in the bodies of living organisms, but after death, decomposer organisms make the materials available to other living things. Decomposers break down the organic matter in dead bodies and feces into small, inorganic molecules. These small molecules pass into the soil or water, where they can become part of the living world at some future time (**Figure 2**).

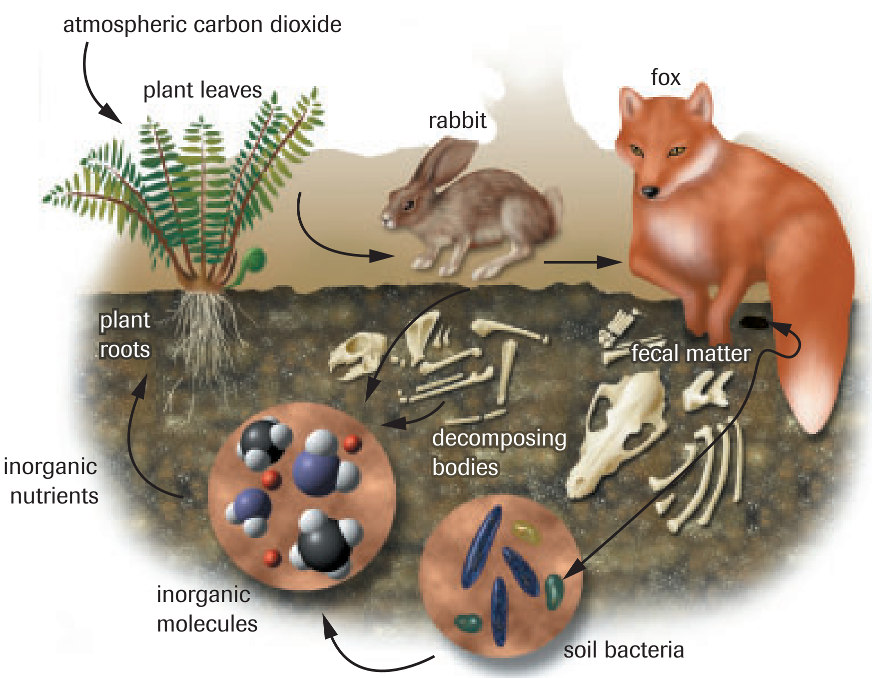


Figure 2
Decomposers break down complex organic molecules into inorganic matter, which may be used by plants. Plants reassemble these inorganic substances (also called nutrients) to make food for themselves. In turn, animals may eat the plants, continuing the cycling of matter.

INVESTIGATION 3.1 ***Introduction***

Nutrient Cycling and Plant Growth

Humans often add nutrients to soil to promote plant growth. In natural ecosystems, soil nutrients are recycled between decomposing matter and growing plants. In this investigation, you will determine which of three samples of different soil types delivers the most nutrients to plants.

Report Checklist

○ Purpose	● Design	● Analysis
● Problem	○ Materials	● Evaluation
○ Hypothesis	○ Procedure	● Synthesis
○ Prediction	● Evidence	

To perform this investigation, turn to page 67.

Properties of Water

All living organisms need water (**Table 1**). Water is the solvent in which most metabolic reactions take place. It is the major component of a cell's cytoplasm. Many organisms live within its stable environment, while others depend on water to carry dissolved nutrients to their cells. The volume of water in the biosphere, including its solid phase (snow or ice) and gaseous phase (vapour), remains fairly constant; however, the specific amount in any one phase can vary considerably. It is continuously entering and leaving living systems.

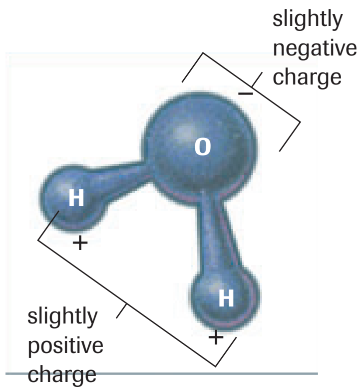


Figure 3
The electrons are pulled closer to the oxygen end of the molecule. The single proton of each hydrogen atom causes a positively charged end.

Table 1 The Importance of Water to Organisms

• Absorbs and releases thermal energy and moderates temperature fluctuations
• Is the medium in which metabolic reactions take place
• Is an excellent solvent
• Makes up over 60 % of the cell's mass
• Supplies hydrogen atoms to producers during the metabolism of key organic molecules during photosynthesis and oxygen atoms to all organisms during cellular respiration
• Is a reactant in some metabolic activities and a product in others

polar molecule a molecule that has a positive and a negative end

hydrogen bond the type of bond that is formed between the positive end of one water molecule and the negative end of another water molecule

Water: A Polar Molecule

Water molecules are held together by covalent bonds that join one oxygen and two hydrogen atoms (**Figure 3**). The electrons are drawn toward the oxygen atom, creating a region of negative charge near the oxygen end of the molecule and a positive charge near the hydrogen end of the molecule. Although the positive and negative charges on the molecule balance each other out, the molecule has a positive pole and a negative pole. It is for this reason that water is referred to as a **polar molecule**. The negative end of a water molecule repels the negative end of another water molecule, but attracts its positive end. Attraction between opposing charges of different molecules creates a special **hydrogen bond**. Hydrogen bonds pull water molecules together (**Figure 4**).

Hydrogen bonding helps explain some of the physical properties of water. Water boils at 100 °C and freezes at 0 °C. By comparison, sulfur dioxide, a molecule of similar size, boils at 62 °C and freezes at −83 °C. The higher boiling point and melting point of water can be explained by the hydrogen bonds. Consider the boiling point of water. Before water molecules can escape into the air, hydrogen bonds must be broken. This requires additional energy. Molecules like sulfur dioxide and carbon dioxide do not have hydrogen bonds. Consequently, they require less energy to boil and have lower boiling points.

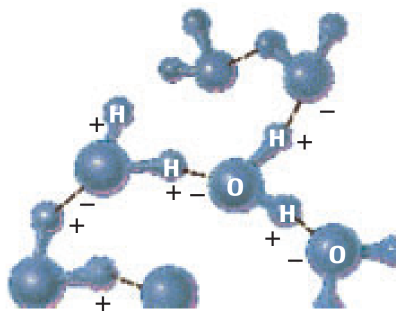


Figure 4
A hydrogen bond is formed between the oxygen end of one water molecule and the hydrogen end of another water molecule.

hydrological cycle (water cycle) the movement of water through the environment from the atmosphere to Earth and back

EXTENSION

Dissociation of Water

Water exists as two atoms of hydrogen attached to an atom of oxygen. However, a small number of water molecules dissociate into two separate ions: a positive hydrogen ion and a negative hydroxide ion. Solutions in which the concentration of hydrogen ions is greater than the number of hydroxide ions are acids. Bases are formed when the concentration of hydroxide ions is greater than the concentration of hydrogen ions. Complete this Extension to review acids, bases, and the pH scale.

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The Hydrological Cycle

The movement of water through the biosphere is called the **hydrological** or **water cycle**, shown in **Figure 5**. Water reaching Earth's surface as precipitation (rain, snow, sleet, hail, or any combination of these forms) can enter a number of pathways. It may remain on the surface as standing water (lakes, swamps, sloughs) or form rivers and streams that eventually flow to the oceans, which form the bulk of the water reserves. Some of the precipitation sinks into the soil and subsurface rock, forming ground water. If the rock is permeable, some of this ground water may seep to the surface, forming springs or adding water to existing lakes and streams. The movement of water through rock is slow but measurable.

By absorbing energy from the Sun, some of the surface water evaporates and becomes water vapour. The water vapour rises upward in the atmosphere until it reaches a point where the temperature is low enough for the water vapour to condense into tiny droplets of liquid water. These droplets are so light that they remain suspended in the atmosphere as clouds, supported by rising air currents and winds. When conditions are right (e.g., the temperature drops), the droplets join together, forming larger drops or ice crystals. Once the mass of the droplet or ice crystal can no longer be supported by air currents, precipitation occurs. This cycle repeats itself endlessly.

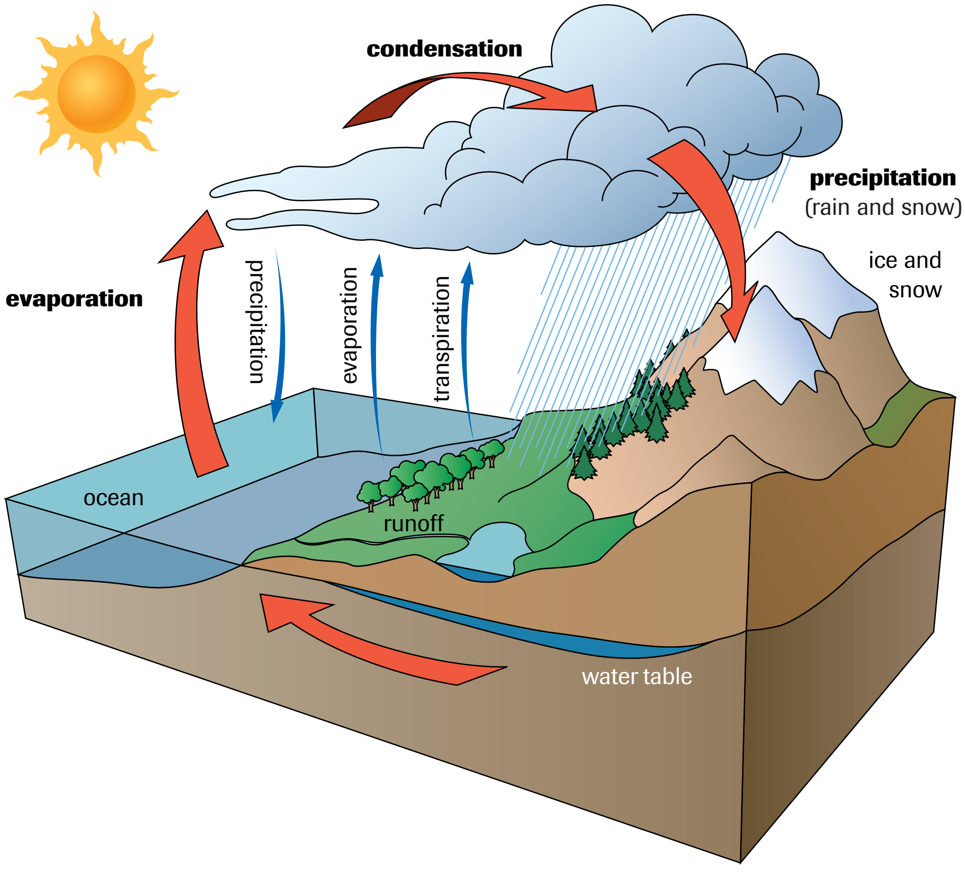

Figure 5
The water cycle

Living organisms also play a vital role in the water cycle. Water enters all organisms and is used by them in various ways during their metabolic activities. You may think that living things tend to remove water from the environment, thus interfering with the cycle. However, through such processes as cellular respiration and the decay of dead organisms, water is released back to the land or atmosphere. Plants, particularly broad-leaf trees and shrubs, play a major role in water recycling through the process of **transpiration**. In fact, where forests have been removed by logging or burning, there is less water in the atmosphere, along with noticeable climate changes. Surface runoff patterns become disturbed and the water-holding capability of the soil may be reduced. This helps explain why the destruction of Brazilian rainforests provides only temporarily usable land for agriculture.

transpiration the loss of water through plant leaves

Water beneath the Soil

The fresh water that we use comes from two sources: ground water and surface water. Precipitation that collects above the ground, such as the water in lakes, ponds, and rivers, is called surface water. Precipitation increases surface runoff, making lakes and rivers rise. In addition, rainfall seeps into the soil. The water filters downward because of gravity. The downward pull of water is called **percolation**. The larger the soil particles are, the greater the size of the pores between the particles and the faster the percolation rate. Eventually, water fills the lower levels of soil, which are composed of sand and gravel. The **water table** forms above a layer of relatively impermeable bedrock or clay. The greater the rainfall, the higher the water table will be.

As water seeps downward, it carries dissolved organic matter and minerals to the lower layers of the soil. The process is called **leaching**. Removing these chemicals from the upper layers of the soil is a serious problem because plants require these nutrients for growth and development. In many ways, plants help correct the problem of leaching. Long branching roots extend deep into soil and help bring minerals and other chemicals from the lower levels of the soil back to the surface.

percolation the movement of a liquid through a porous material, such as soil particles

water table the top level of the region below the ground that is saturated with water

leaching the removal of soluble minerals by percolation

mini *Investigation* — *Measuring Water Loss from Leaves*

Plants contribute to the water cycle by moving water from their roots to the atmosphere, through pores in their leaves. Do all plant species contribute at the same rate?

Materials: balance, small clear, plastic bags with twist-ties, access to coniferous and deciduous trees and other living plants

- Find the mass of two small plastic bags. Place one bag around a leaf of a growing deciduous tree and another around a small branch from a coniferous tree (**Figure 6**).
- Gently tie off the bags and collect water for 24 hours.
- Find the mass of the bags.

(a) In which bag was the most water collected?
(b) Provide reasons to explain the difference.
(c) Design an activity to measure water consumption and loss in animals.
   (i) Identify the responding and manipulated variables.
   (ii) What variables must be controlled?
   (iii) Write a possible laboratory procedure.

Figure 6

CAREER CONNECTION

Environmental Auditor

Environmental auditors work to make sure that industries and corporations are meeting environmental standards and regulations. They help to detect potential environmental concerns and to monitor business activities that might have environmental impacts. These specialists also oversee remediation activities and make recommendations to environmental organizations.

Find out more about this important and meaningful career, including the educational requirements.

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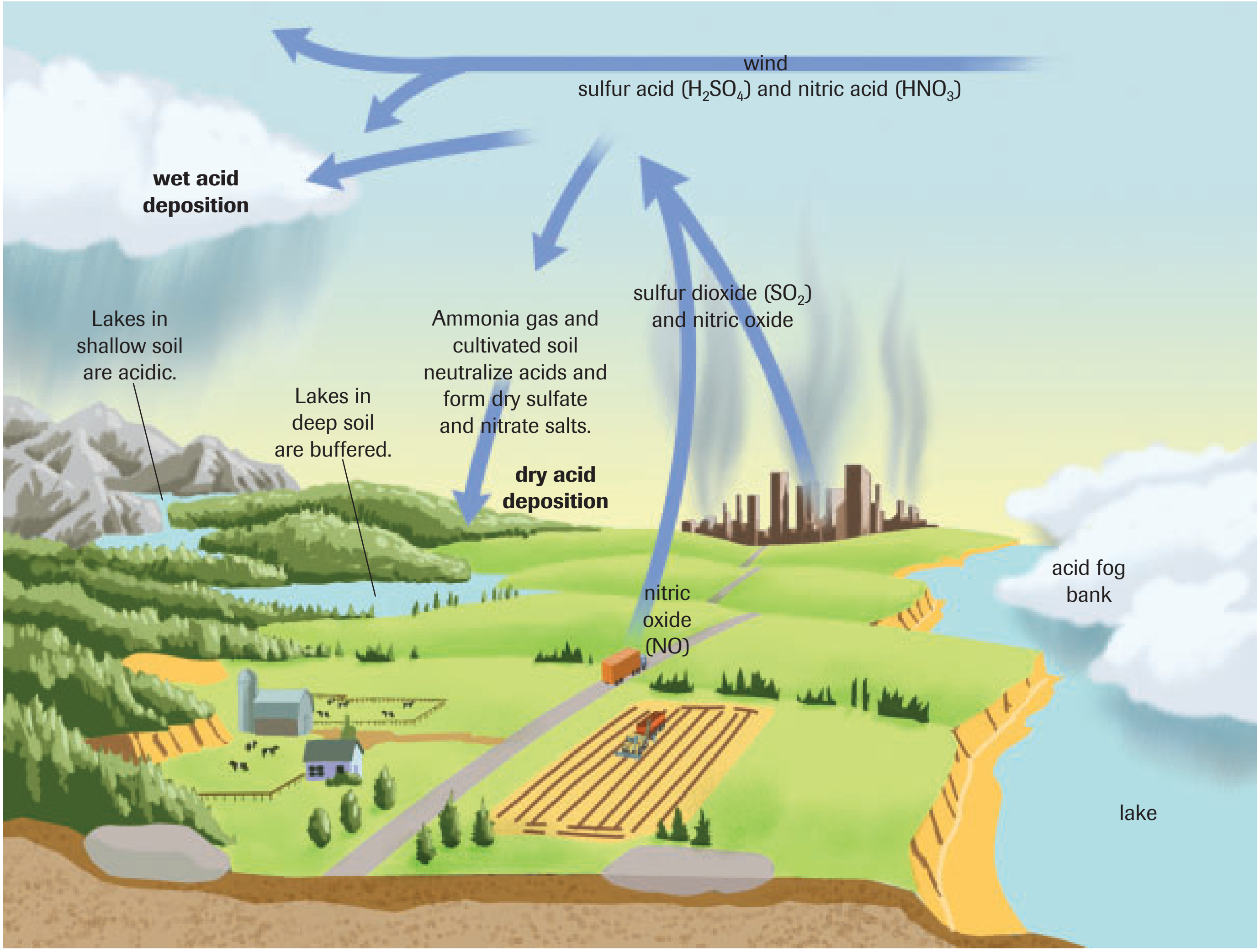
Acid Deposition and the Water Cycle

Although society obtains many benefits from technology, there is almost always an environmental price to pay. Nowhere is this more evident than with the technologies that contribute to acid deposition. Smokestacks of coal-burning generating stations, metal smelters, and oil refineries provide energy and products for the industrial world, but at the same time produce oxides of sulfur and nitrogen, some of the most dangerous air pollutants.

When fossil fuels and metal ores containing sulfur are burned, the sulfur is released in the form of sulfur dioxide (SO_2), a poisonous gas. Combustion in automobiles and fossil fuel-burning power plants, along with the processing of nitrogen fertilizers, produce various nitrous oxides (NO_x). Sulfur dioxide and nitrous oxides enter the atmosphere and combine with water droplets to form acids. The acids return to the surface of Earth in the form of snow or rain, called "acid rain" (**Figure 7**).

Acid rain has been measured to be as much as 40 times more acidic than normal rain. The devastation of acid rain on ecosystems has been well documented. Acid precipitation kills fish, soil bacteria, and both aquatic and terrestrial plants, as shown in **Figure 8**, on the next page. It leaches nutrients from the soil by dissolving them in the ground water. The devastation is rarely uniform; some ecosystems are more sensitive than others. Alkaline soils neutralize the acids, minimizing their impact. The moun-

Figure 7
Wet and dry acid deposition



tains of British Columbia are limestone, which help to counter the effect of the acid. Thus, Alberta's rivers are not very acidic. Soils in much of southeastern Canada, however, lie over a solid granite base, which does little to balance the acid.

The sulfur and nitrous oxides released from smokestacks do not always enter the water cycle in the atmosphere. Depending on weather conditions, particles of sulfur and nitrogen compounds may remain airborne and then settle out in the dry state, or as "dry deposition." These dry pollutants, then, form acids when they combine with moisture on a surface, such as the dew on a lawn, the surface of a lake, or the water inside your respiratory tract.

Technology offers some solutions to the problems that have been caused by emitting oxides of sulfur and nitrogen. "Scrubbers" in smokestacks now remove much of the harmful emissions, and lime has been added to lakes in an attempt to neutralize acids from the atmosphere. However, both of these solutions are expensive. The prospect of improving smelters is equally difficult. Mining companies are already battling to remain operational and compete in a world market. Many developing countries are producing ores at a much lower cost because of cheaper labour and more relaxed environmental standards. Tougher legislation could result in higher levels of unemployment.

Figure 8
Devastation of forests caused by long-term exposure to acid rain. Conifers are particularly susceptible to acid, which makes them vulnerable to a variety of infections.

The Role of Water in Nutrient Cycling

As you have just seen, many harmful substances are transported when dissolved in water. In the next two sections, you will see that water also plays an essential role in the cycling of other substances throughout the biosphere. Since it is such an excellent solvent, water can dissolve nutrients such as nitrates and phosphates, enabling plant roots to absorb them. Because of hydrogen bonding, water can move against gravity, carrying nutrients up plant stems and trunks to cells throughout the plant. This upward motion of water is called "capillary action." Water has a role in the cycling of carbon and oxygen as well. For example, water dissolves carbon dioxide and oxygen, bringing these gases to organisms in aquatic ecosystems. Because water can dissolve carbon dioxide, the ocean stores vast amounts of carbon. Water is also an essential factor in photosynthesis and cellular respiration, two processes that form the backbone of carbon and oxygen cycling in the biosphere.

WEB Activity

Web Quest—Pesticides: Pro or Con?

Pesticides are chemicals that protect our crops from damage by insects and disease-causing organisms. Although they were developed to improve human life, this protection also has a price. Instead of contributing to the cycling of matter, many pesticides persist in the environment for long periods. Many people now believe that pesticides cause more harm than good. In this Web Quest, you will explore the costs and benefits of pesticides, and then make a well-supported decision about where you stand on this issue.

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SUMMARY The Hydrological Cycle

- Polar molecules, such as water, are molecules with a positive and a negative end. Hydrogen bonds are formed between the positive end of one water molecule and the negative end of another water molecule.
- The hydrological cycle or water cycle is the movement of water through the environment from the atmosphere to Earth and back.
- The hydrological cycle traces the phase changes of water in the abiotic environment and follows its role in living organisms.
- Sulfur dioxide and nitrous oxides enter the atmosphere and combine with water droplets to form acids. The acids return to the surface of Earth in the form of snow or rain, called "acid precipitation."
- Water plays an important role in the cycling of nutrients in the biosphere.

Section 3.1 Questions

1. (a) What two types of atoms are contained in all organic compounds?
(b) Oxygen atoms are part of many organic compounds. How might these atoms enter the body of a living thing?
(c) Many organic compounds also contain nitrogen and phosphorus atoms. How might these atoms enter the body of a living thing?
(d) What are three ways that matter leaves the bodies of living things?

2. Using diagrams, show two different ways that a carbon atom that was once in a cell in a grass leaf could become part of a cell in your ear.

3. In a few paragraphs, explain the diagram in **Figure 9**.

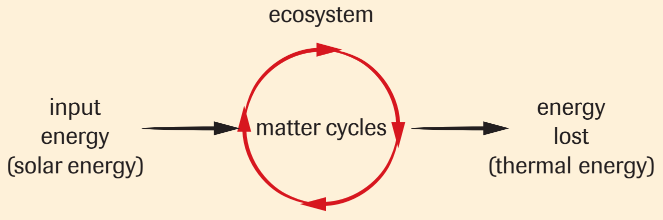

Figure 9

4. When space probes were sent to the Moon and Mars, soil samples were collected and analyzed for organic compounds. Why would scientists want to know if organic matter were present in these soil samples?

5. The following sentence is found in the opener of of this chapter: "By changing constantly, ecosystems can remain stable, in a dynamic equilibrium, or balance." Using a grassland ecosystem as an example, explain what is meant by dynamic equilibrium.

6. Predict what would happen to a deciduous forest ecosystem if an agent were released that destroyed decomposing bacteria found in the soil.

7. Why is water important to living things?

8. Using water as an example, define polar molecules.

9. What is a water table?

10. How does the water cycle purify water samples?

11. Why do minerals leach from the soil?

12. Identify and describe two factors that would alter the amount of ground water in an area.

13. How do the roots of plants help prevent the leaching of important minerals?

14. Describe the danger of digging a hole for an outhouse at a beach cottage.

15. How could a landfill site contaminate ground water?

16. Natural and genetically engineered bacteria and fungi can be used to either destroy toxic chemicals or convert them to harmless forms. The process, referred to as bioremediation, mimics nature by using decomposers to recycle matter. Research how bioremediation is used to clean up various pollutants, and report on your findings.

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17. List abiotic characteristics of an ecosystem that make it particularly vulnerable to the effects of acid deposition. Predict the long-term effects of such deposition.

The Carbon Cycle and the Oxygen Cycle 3.2

Carbon is the key element for living things. Carbon can be found in the atmosphere and dissolved in the oceans as part of the inorganic carbon dioxide (CO_2) molecule. Each year, 50 to 70 billion tonnes of carbon from inorganic carbon dioxide are cycled into more complex organic substances. This is done through photosynthesis (see Chapter 2). Some of the organic carbon is released back to the atmosphere through cellular respiration as carbon dioxide.

Because photosynthesis and cellular respiration are complementary processes, and because the carbon that they use is repeatedly cycled through both processes, this relationship is often called the **carbon cycle**. This cycle is actually much more complex than a simple exchange of carbon-as-carbon-dioxide and carbon-as-glucose (**Figure 1**). Most of the carbon in living organisms is returned to the atmosphere or water as carbon dioxide from body wastes and decaying organisms. However, under certain conditions the decay process is delayed and the organic matter may be converted into rock or fossil fuels such as coal, petroleum, and natural gas. This carbon is then unavailable to the cycle until it is released by processes such as uplifting and weathering, or by burning as fuels. The burning process (**combustion**) releases carbon dioxide into the atmosphere.

carbon cycle the cycle of matter in which carbon atoms move from an inorganic form to an organic form and then back to an inorganic form

combustion the chemical reaction that occurs when a substance reacts very quickly with oxygen to release energy

Reservoirs for Inorganic Carbon

When it is not in organic form, carbon can be found in three main reservoirs (storage areas): the atmosphere, the oceans, and Earth's crust. The smallest of these reservoirs is the atmosphere. Carbon dioxide makes up a very small percentage (about 0.03 %) of the gases that we breathe in. However, there is plenty of atmospheric carbon dioxide for land plants to use in photosynthesis.

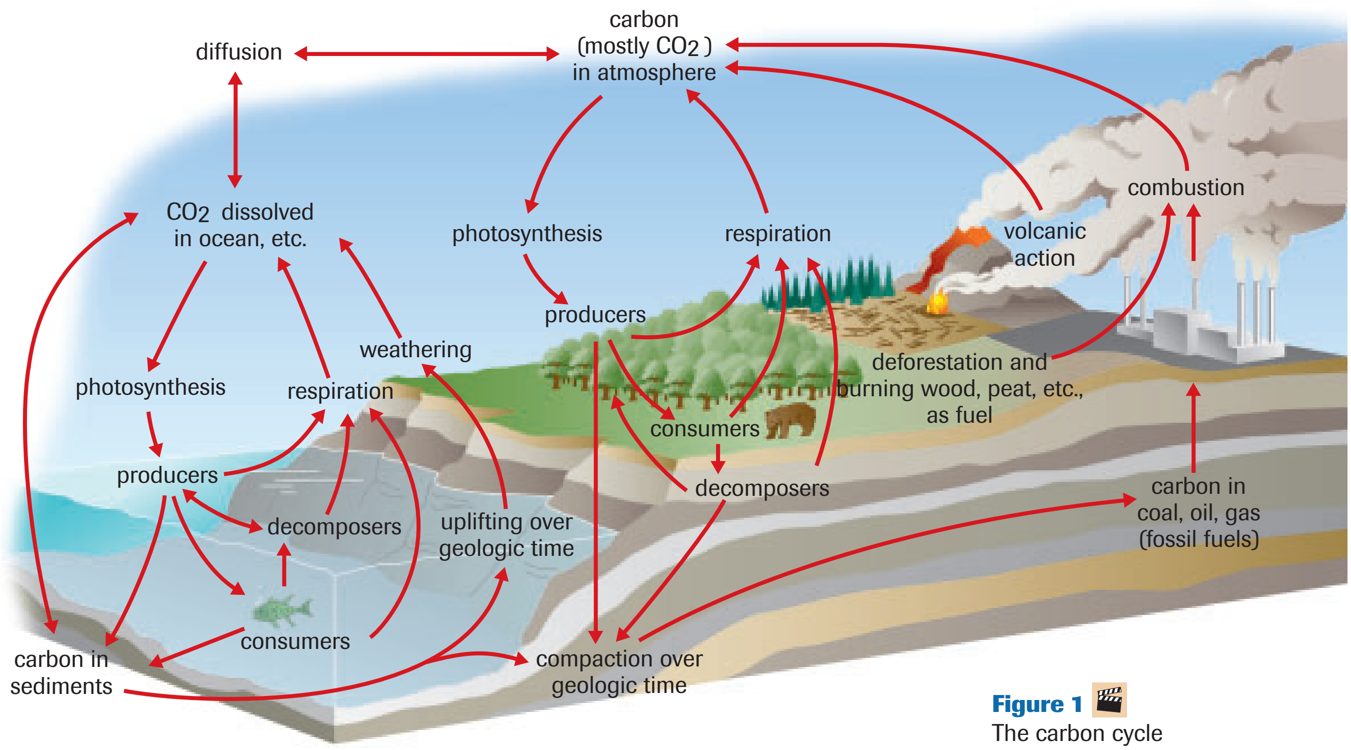

Figure 1
The carbon cycle

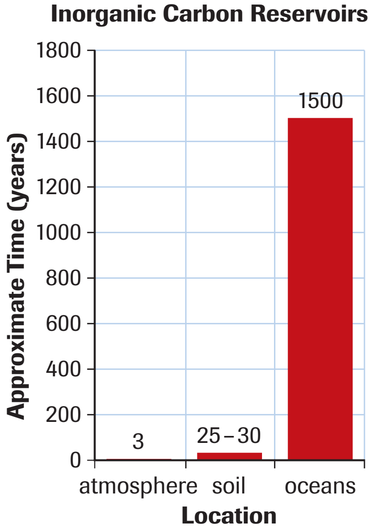

Figure 2
The average carbon atom is held in inorganic form much longer in the ocean than in the atmosphere. The time for carbon held in rocks (millions of years) would not fit well in this graph.

A tremendous amount of inorganic carbon is held as dissolved carbon dioxide in the oceans, where it is available to algae and other water plants for photosynthesis. However, some carbon dioxide reacts with sea water to form the inorganic carbonate ion (CO_3^{2-}) and the bicarbonate ion (HCO_3^-). Combined with calcium, these ions become calcium carbonate ($CaCO_3$), which is used by living things to make shells and other hard structures. The carbon in carbonates can be recycled, but in the ocean much of it ends up as sediment. As layers of sediment form, the carbonates are crushed and heated and eventually become rock. Limestone is made from the discarded shells and bones of living things. This explains why by far the largest reservoir of Earth's carbon is in sedimentary rocks. Carbon can be trapped in rock for millions of years until geological conditions bring it back to the surface. Volcanic activity can break down carbonate-containing rocks such as limestone, releasing carbon dioxide. Acid rain falling on exposed limestone will also cause the release of carbon dioxide into the atmosphere.

Figure 2 shows how long, on average, a carbon dioxide molecule will remain in each reservoir.

Reservoirs for Organic Carbon

Organic carbon is also held in reservoirs—the bodies of living things. However, all living things die, and decomposition eventually returns the carbon to the cycle in inorganic form. There is one important exception to this rule: some ecosystems, such as bogs, store huge quantities of carbon in organic form. Bogs contain very little oxygen, and under these conditions decomposition is very slow. Carbon atoms may remain locked away in dead plant matter (**peat**) for many years in a bog. Occasionally these deposits are overlaid with sediment. As more layers of sediment are piled on top, the slowly decaying organic matter can end up trapped between layers of rock. The result is the formation of a carbon-containing fossil fuel, coal (**Figure 3**).

peat slowly decomposing plant matter produced in low-oxygen environments such as bogs

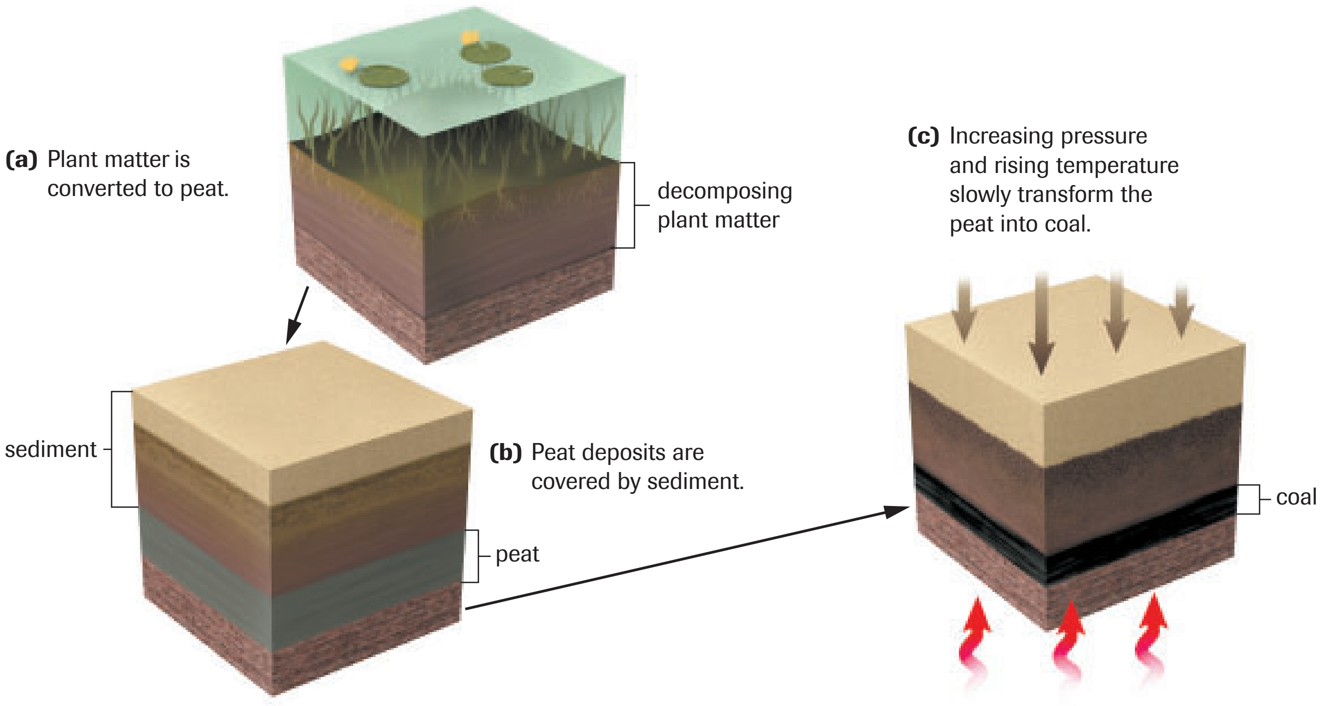

Figure 3
Coal is a reservoir of organic carbon that can be stored in Earth's crust for millions of years before cycling again into carbon dioxide.

Conditions similar to those in a bog also exist on the floors of oceans; organic carbon can also be trapped there for long periods. Oil is formed in a process similar to the formation of coal, when decaying aquatic animals and plants are trapped under sediment in a low-oxygen environment.

In the form of fossil fuels in Earth's crust, organic forms of carbon can be held out of the carbon cycle for many millions of years.

LAB EXERCISE 3.A

Carbon Dioxide Production by Plants and Animals

Through photosynthesis, plants take up carbon dioxide and release oxygen. Both plants and animals carry out cellular respiration, which uses oxygen and releases carbon. Plants and animals, therefore, could have very different effects on the cycling of carbon. Carbon dioxide produced by aquatic species dissolves in the water in which they live. Bromothymol blue is an indicator used to show the presence of carbon dioxide in solution. Low levels of carbon dioxide will result in the bromothymol blue solution remaining blue, while higher levels of carbon dioxide will cause the dye to change to yellow. In this lab exercise, you will use the given list of materials to design an investigation to compare the carbon dioxide production of plants and animals.

Report Checklist

- ○ Purpose
- ○ Problem
- ○ Hypothesis
- ○ Prediction
- ● Design
- ○ Materials
- ○ Procedure
- ○ Evidence
- ○ Analysis
- ○ Evaluation
- ○ Synthesis

Purpose

To compare carbon dioxide production of plants and animals

Problem

Do plants and animals contribute similar amounts of carbon dioxide to the carbon cycle?

Materials

8 test tubes
water
4 aquatic snails
8 stoppers
bromothymol blue solution
4 stalks of *Elodea*
light source
timer

Design

Design an experiment to address the Problem. Ensure you include the manipulated variable and controlled variables in your design.

The Oxygen Cycle

Since oxygen is an integral part of both photosynthesis and cellular respiration, the cycling of oxygen in the biosphere is closely linked to the cycling of carbon. In general, the oxygen cycle on Earth consists of the movement of oxygen gas, O_2, from living things into the atmosphere through photosynthesis, and then back into living things through cellular respiration. However, this description of the oxygen cycle is very simplified. Oxygen atoms cycle in the atmosphere between oxygen gas and ozone, O_3. Oxygen atoms are also present in carbon dioxide, water, glucose, and many other important substances. In addition, oxygen gas plays a part in many reactions. As a result, the oxygen cycle is extremely complex. Oxygen can be found in living things, in the atmosphere, in water, and in many types of rock. In fact, most of Earth's oxygen is stored in the rock of the lithosphere. Oxygen is needed by most living things for cellular respiration, and as part of the decomposition process.

EXTENSION

Interpreting Changes in the Ozone Layer from Satellite Images

Human industry has also affected the amount of ozone in our atmosphere. In this Extension, you will investigate the ozone layer and its changes over time.

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Figure 4
The burning of the rain forest disrupts the balance between photosynthesis and cellular respiration. Many human activities affect the carbon cycle.

Human Impact on the Carbon Cycle

Over the past century, humans have mined fossil fuels trapped in Earth's crust and burned them. This has modified the global carbon cycle by releasing carbon from organic reservoirs faster than would normally occur.

Humans are also increasing the amount of carbon dioxide in the inorganic reservoir of the atmosphere by clearing away vegetation in order to build or farm. The destruction of vegetation reduces the amount of photosynthesis, and so reduces the amount of carbon dioxide removed from the atmosphere (**Figure 4**). Most carbon dioxide released into the air eventually becomes dissolved in the oceans, but the oceans can hold only so much. The amount of carbon dioxide in the atmosphere is rising.

The Greenhouse Effect

Have you ever noticed how hot it can get in a car on a sunny day? Every year, dogs and cats are killed when their owners leave them in closed cars. The heating is caused by the greenhouse effect. The shorter wavelengths of sunlight (primarily infrared) enter the car (acting just like a greenhouse) through the glass. These are absorbed and re-radiated as longer wavelengths. The reflected light is prevented from escaping by the glass. The car (or greenhouse) heats up.

Many of the atmospheric gases that surround Earth, such as CO_2 and CH_4, act like the glass of the greenhouse shown in **Figure 5**. The gases trap the heat from the Sun and warm Earth's surface. A certain amount of "greenhouse gas" is essential for the survival of life on Earth. Without greenhouse gases, the average temperature of the planet would fall from 15 °C to −18 °C.

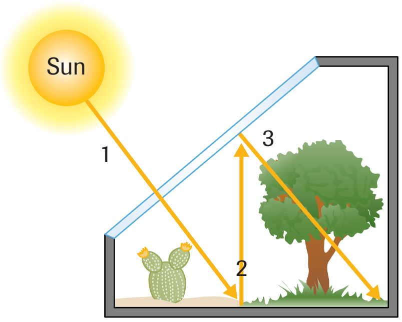


Figure 5
The greenhouse effect: 1. Shorter wavelengths of sunlight enter the greenhouse. 2. Light is reflected and wavelengths become longer. 3. The longer wavelengths are trapped by the glass.

Global Warming

The increased energy demands of an industrialized world have brought about more factories that produce smoke and more automobiles that release exhaust. Carbon dioxide is released during combustion. Scientists estimate that the burning of wood and fossil fuels (coal, oil, and gas) has caused carbon dioxide levels to triple over the past 40 years. Global temperatures have increased by 1 °C over that same time. The rising levels of carbon dioxide, one of the main greenhouse gases, have changed the balance between photosynthesis and cellular respiration (**Figure 7**, next page).

mini *Investigation* — *Greenhouse Effect Simulation*

The greenhouse effect can be simulated by the following experiment.

Materials: ice cubes, 2 plastic bags, 2 small thermometers, 1 large glass jar, clock or timer, 100 mL graduated cylinder

- Put the same mass of ice cubes in two separate plastic bags.
- Place a small thermometer inside each bag to record the air temperature.
- Place one of the bags inside a large glass jar and allow it to sit in sunlight. Put the second bag beside the first, but not enclosed in glass (**Figure 6**).

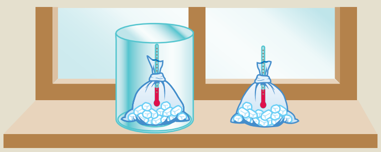


Figure 6

- After 10 min, remove the first bag from the glass jar. Record the air temperatures inside both bags.
- Use a graduated cylinder to measure the amount of melting that has occurred.

(a) Present your data.
(b) State your conclusions.

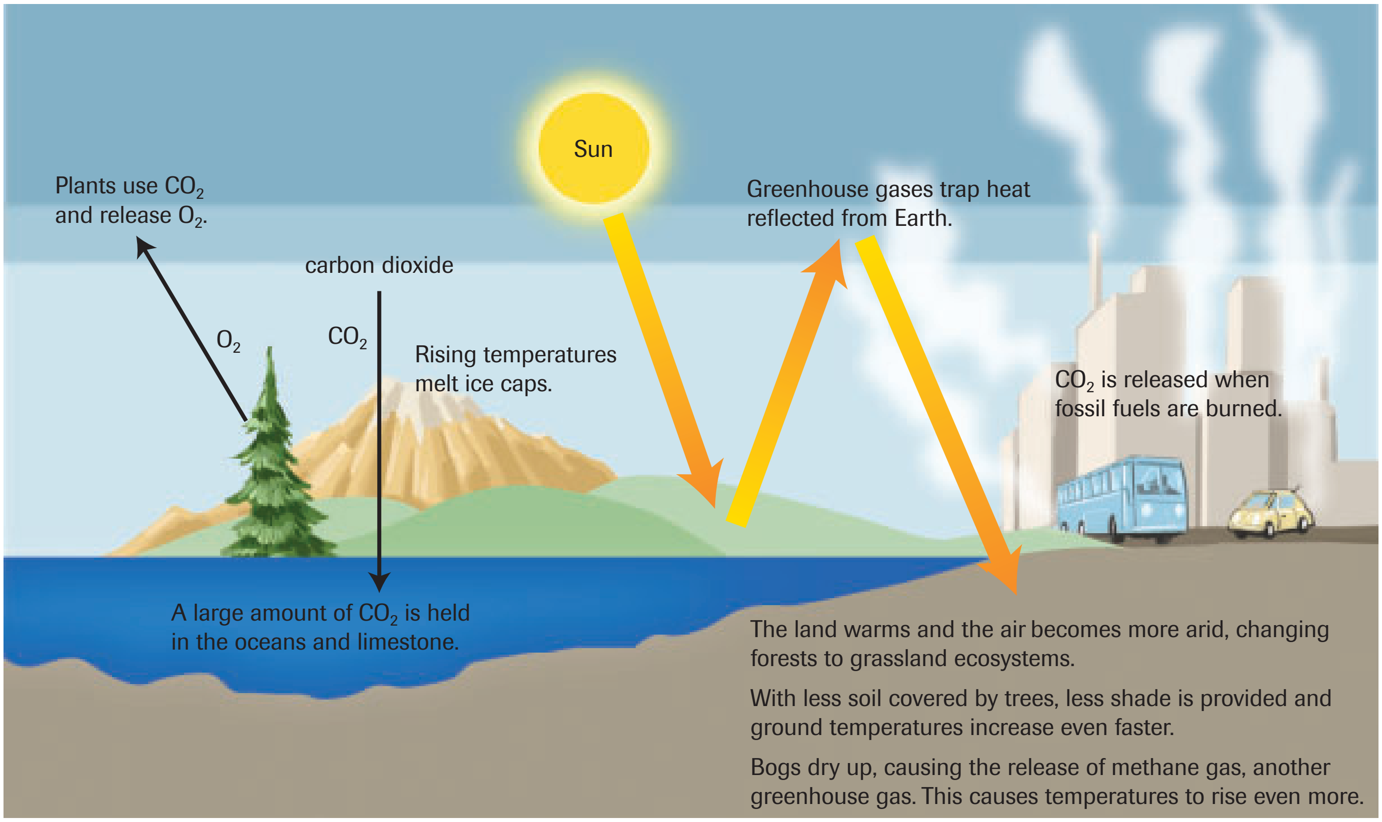


Figure 7
Effects of increases in carbon dioxide levels in the atmosphere

A Warmer Climate

The prospect of increased temperatures may seem appealing to most Canadians. However, increased temperatures can bring several ecological problems. In Canada's high Arctic, the layer of ground that remains permanently frozen would thaw, causing the collapse of many roads and buildings that rely on frozen ground for support. Snowcaps would melt and rivers would overflow, causing flooding in many of our cities. The melting snow and glaciers would also raise the level of the world's oceans, causing drastic changes in coastal areas.

Port cities like Halifax and Vancouver would find much of their waterfront real estate under water. Cities that border large lakes or have rivers would experience greater fluctuations in water levels. The city of Winnipeg has many neighbourhoods that are regularly affected by flood waters from the Red and Assiniboine Rivers (**Figure 8**). This flooding could become worse.

Figure 8
Because so many Canadians live close to large bodies of water, scientists believe that global warming could cause enormous property damage.

The Albedo Effect

If global warming continues to increase, scientists fear that much of the world's permanent ice and snow cover will melt. As mentioned earlier, the melting of polar ice caps will increase the level of Earth's oceans. What other effects could the loss of ice and snow have on the biosphere?

As radiation from the Sun reaches Earth, it is reflected back by Earth's surface. Some surfaces reflect radiation more than others. The term **albedo** is used to describe the extent to which a surface can reflect radiation. The higher the albedo, the greater the ability to reflect radiation. This principle can be applied to the solar radiation striking Earth's surface. The higher the albedo of the surface, the less energy will be absorbed.

albedo a term used to describe the extent to which a surface can reflect light that strikes it. An albedo of 0.08 means that 8 % of the light is reflected.

Snow and ice have a valuable role in maintaining temperatures on Earth. The albedo of snow and ice cover is extremely high. During winter, the Sun's energy reflects off snow, keeping temperatures low. Snow is part of a cycle known as snow-temperature feedback (**Figure 9**). To picture this cycle, think of an area that is covered in snow. If that area warms up, the snow will melt. Less of the sun's radiation will be reflected, so more radiation will be absorbed. The temperature in the area will increase even more.

Some parts of Earth are permanently covered in snow or ice. If Earth's overall snow and ice cover decreases due to global warming, Earth's surface could absorb more heat, and warm up even more. The snow-temperature feedback cycle works the opposite way, as well. For example, if Earth's temperature were to drop during an ice age, more snow would cover Earth's surface, reflecting more of the Sun's radiation. The temperature would continue to drop.

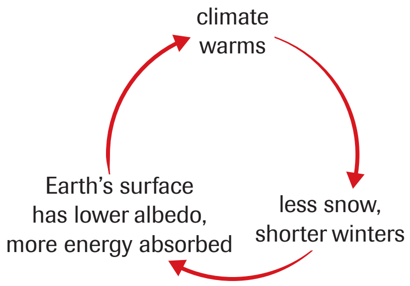


Figure 9
The snow-temperature feedback cycle

INVESTIGATION 3.2 *Introduction*

The Albedo Effect

The albedo of a surface is affected by various factors, including colour and surface conditions. In this investigation, you will measure the amount of light reflected when the colour and texture of a surface is varied.

Report Checklist

○ Purpose	○ Design	● Analysis
○ Problem	○ Materials	● Evaluation
○ Hypothesis	○ Procedure	● Synthesis
○ Prediction	● Evidence	

To perform this investigation, turn to page 68.

Equilibrium and Earth's Atmosphere

The levels of carbon dioxide and oxygen change little from year to year. However, when these levels are examined over the life of the planet, dramatic changes in the carbon cycle show how living things, Earth's crust, and the atmosphere interact to alter the biosphere. Initially, Earth contained exceedingly high concentrations of CO_2, causing the planet to warm. About 3.5 billion years ago, microscopic marine life began consuming CO_2 and releasing methane. Fossils of these bacteria can be found in rocks called **stromatolites**. Stromatolites are banded limestone structures that contain colonies of marine bacteria.

stromatolite a banded limestone structure containing fossilized bacteria

Many researchers believe that the methane-producing bacteria poured about 600 times the amount of methane into the skies as is found today. That amount of methane, another greenhouse gas, would have increased the temperature of the planet even more. According to this theory, the warmer conditions of the planet in turn increased the population of methane-producing bacteria, causing more methane to be produced and the temperature to rise even more, in a positive feedback loop (**Figure 10**).

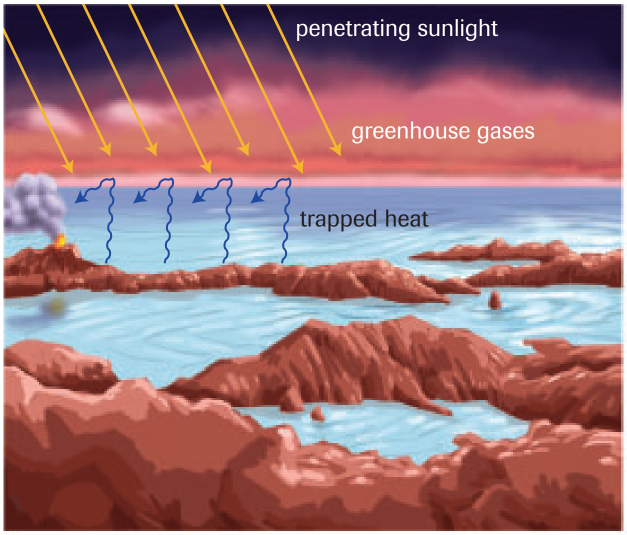
Warmer conditions intensified the water cycle and accelerated the weathering of rocks, a process that pulls CO_2 from the atmosphere. The CO_2 concentrations began to fall and methane production continued to rise. Eventually, the methane gas formed a haze over the planet, deflecting incoming sunlight, and causing temperatures to drop. This made conditions less favourable for the methane-producing bacteria.

DID YOU KNOW?

The Kyoto Accord

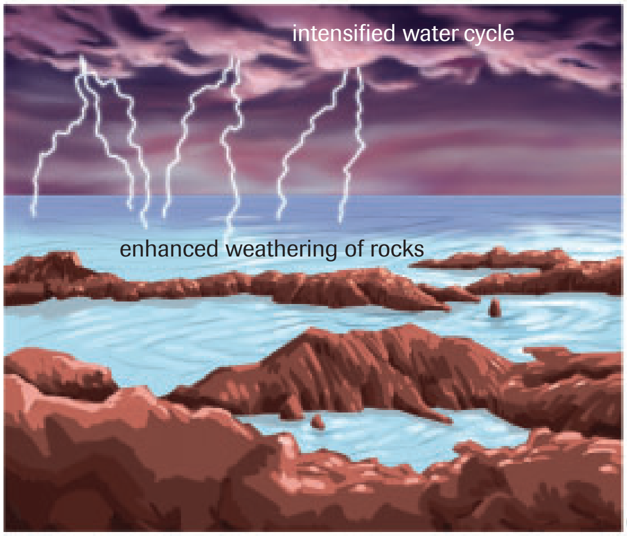
The Kyoto Accord is an international agreement to reduce greenhouse gas emissions. It calls for Canada to reduce emissions to 6 % below 1990 levels over a period of 10 years. Why does the government of Alberta oppose Kyoto's targets? What is your own opinion? Visit the Nelson Web site to learn more about Alberta's response to the Kyoto Accord.

www.science.nelson.com GO

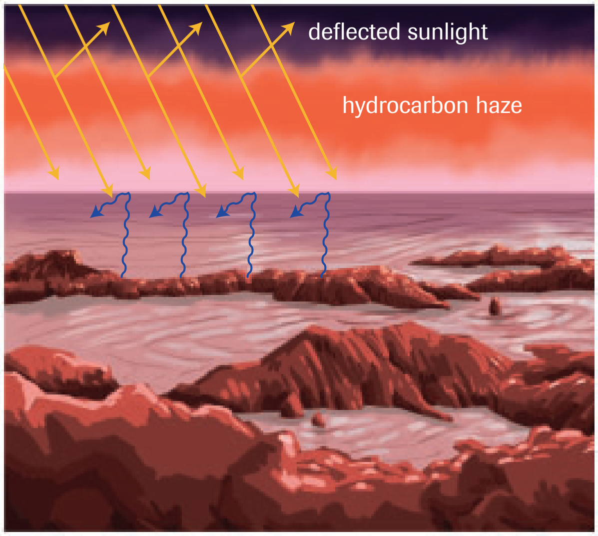


(a)

Figure 10
Earth's early atmosphere.
(a) The greenhouse gases carbon dioxide (from volcanoes) and methane (from bacteria) trapped heat while allowing sunlight to penetrate.
(b) Warmer temperatures accelerated the water cycle and increased the weathering of rocks. The process caused CO_2 to be absorbed from the atmosphere. CO_2 levels dropped and methane increased.
(c) A methane haze blocked sunlight and lowered temperatures. Lower temperatures made conditions less favourable to methane-producing bacteria.



(b)



(c)

EXTENSION

Causes of the Greenhouse Effect

This Audio Clip provides some deeper information about the causes and global impacts of the greenhouse effect.

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The decline in methane-producing bacteria, approximately 2.3 billion years ago, was accompanied by the appearance of another life form capable of withstanding the cooler temperatures. These photosynthetic bacteria released oxygen. Eventually, the hardier oxygen-producing bacteria overtook the methane-producing bacteria. As oxygen levels began to increase, more complicated life forms could be supported.

Deforestation and the Atmosphere

In the distant past, changes in the populations of living things resulted in changes to Earth's atmosphere. Large-scale changes are happening to populations of trees and other plants at the present time. How will these changes affect the atmosphere?

Human activities are reducing the number of organisms on Earth that carry out photosynthesis. For example, logging reduces the amount of forested area, and land development decreases the space available for plants to grow. Photosynthesis is the source of oxygen in our atmosphere, and also removes carbon dioxide gas from the atmosphere. With less photosynthesis happening on Earth, oxygen levels will decrease, and carbon dioxide levels will increase even more. Protecting forests on Earth is, therefore, essential to preserving our atmosphere.

INVESTIGATION 3.3 ***Introduction***

Environmental Models

Report Checklist

- ○ Purpose
- ● Problem
- ● Hypothesis
- ● Prediction
- ● Design
- ○ Materials
- ● Procedure
- ● Evidence
- ● Analysis
- ● Evaluation
- ○ Synthesis

Environmental models allow scientists to study what could happen to the plants and animals in an ecosystem if changes occur. Models help check predictions without disrupting a large area.

In this investigation, you will build an ecocolumn to research an environmental problem. An ecocolumn is an ecological model that is especially designed to cycle nutrients. You must investigate one of three different environmental problems in the ecocolumn. You must design your own procedure, collect your own data, and draw your own conclusions.

To perform this investigation, turn to page 69.

Case Study

Technological Solutions for Global Warming

More than 200 years ago, Earth's atmosphere contained about 280 parts per million (ppm) of carbon dioxide. By 1993, the burning of fossil fuels had raised the level of carbon dioxide to 355 ppm. At our present rate, the projected concentration of carbon dioxide could be 700 ppm by 2050.

The vast majority of scientists believe that this increase in atmospheric carbon dioxide is increasing the greenhouse effect and contributing to global warming. However, indirect evidence suggests that global fluctuations in temperature and carbon dioxide levels occurred even before humans appeared on the planet. About 135 million years ago, the levels exceeded 1000 ppm, considerably higher than current levels.

As the effects of global warming become more apparent, scientists have developed several potential solutions, using mini-ecosystems and computer models to test various hypotheses. This Case Study presents several suggested solutions. However, no plan is without problems. Think about each technological fix below, and consider its consequences.

Using "Sun Block"

The eruption of Mount Pinatubo in 1991 shot a plume of ash and debris 20 km into the atmosphere. Within three years, even the smallest particles had returned to Earth. Climatologists estimate that this ash blanket cooled global temperatures by about 0.7 °C, at least in tropical areas.

Putting more particles into the atmosphere was suggested by Dr. S.S. Penner, a retired professor from the University of California at San Diego, as a way to cool the planet. Running jet engines on a richer mixture of fuels would add particles to the atmosphere (**Figure 11**). Burning coal also adds soot to the air. This partial screen would be inexpensive. Eventually, the particles would fall to Earth so the air would not remain polluted.

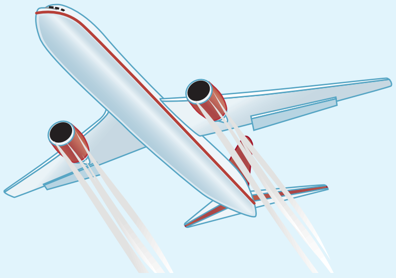

Figure 11

Adding Iron to Sea Water

For many years, naturalists have observed that certain areas of the open ocean are rich in life, while other areas appear barren. After a 7 km^2 patch of ocean off the coast of South America was sprayed with half a tonne of iron, it soon turned green with phytoplankton (**Figure 12**). The experiment, conducted in 1995, caused a bloom of marine plants that perform photosynthesis. Adding iron to seawater could increase photosynthesis and use up some of the CO_2 in the atmosphere.

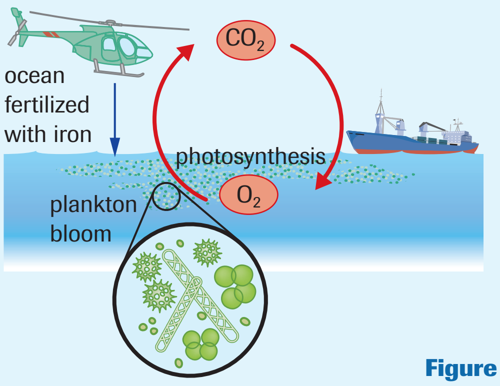

Figure 12

Creating a Deep-Water "Grave" for Carbon Dioxide

An oil company in Norway came up with a revolutionary method to reduce CO_2 levels. Normally, the CO_2 that escapes during the processing of natural gas is released into the air. In 1991, a new carbon tax made this very expensive in Norway. Norwegian companies had to find alternatives.

Natural gas is pumped into a tall tower where the carbon dioxide is removed (**Figure 13**). Almost 1 km below the seafloor, a pipe carries the CO_2 to a layer of shale. The CO_2 displaces seawater from the porous shale, forming a gas bubble in the rock. The CO_2 takes several hundred years to move through the shale to the seafloor.

Scientists point out that most of the floor of the North Sea is sandstone, capped with a layer of shale. This is ideal for the storage of excess carbon dioxide. On a large scale, it could soak up all of the excess CO_2 produced by countries of the European Union. One of the main dangers is that the CO_2 will combine with water to form a weak acid around the pipe.

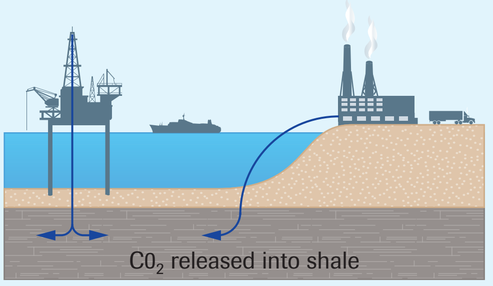

Figure 13
The shale acts as a sink for carbon dioxide gas.

Case Study Questions

1. What groups in Canada might not favour reducing carbon emissions? Provide at least one concern that might be voiced.
2. Why would ash and other particles in the atmosphere cool temperatures?
3. What are some of the possible problems with adding ash and other particles to Earth's atmosphere?
4. How could more algae in Earth's oceans lower global temperatures?
5. What negative effects could increasing the ocean's algae population have on the ecosystem?
6. Why would the formation of weak acids around pipes used to carry carbon dioxide beneath the ocean floor be dangerous?
7. Passing a bylaw saying that people must car pool or take public transportation could reduce fossil fuel usage. Make a list of benefits and problems if this law were instituted.
8. What are the major sources of carbon dioxide in Canada? And what are Canadians doing about the problem of carbon dioxide production? Do research, and then write a short paragraph answering these questions.

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WEB Activity

Case Study—Biosphere 2

On September 26, 1991, four men and four women entered a gigantic dome near Tucson, Arizona, that contained 3800 species of plants and animals. The dome was sealed after they entered. They were to live there for one year. Nothing was to be brought in and nothing, and no one, would be allowed out. All raw materials and waste products were to be recycled by humans, animals, and plants living together. Named Biosphere 2, the dome was the largest and most expensive artificial ecosystem ever created.

Unfortunately, the experiment demonstrated in a fairly short time that we do not know everything we need to know about Earth's ecosystems to fulfill this goal. Despite careful planning to ensure the right numbers of plants and animals, and the use of computer simulations and electronic monitoring devices, the amount of carbon dioxide in the air inside the dome kept increasing. Scientists were not able to establish a workable balance between the number of plants and animals. On November 12, the team running the experiment gave up and pumped in purified air from the outside.

In this Web Activity, you will explore what caused the initial failure of the Biosphere 2 experiment, and find out how the facility is being used today to increase our understanding of the interactions among biotic and abiotic factors in ecosystems.

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EXTENSION

CBC radio ONE QUIRKS & QUARKS

A Carbon Sinking Feeling

Dr. Werner Kurz (team leader at Essa Technologies and an adjunct professor at the University of British Columbia and Simon Fraser University) discusses the idea that carbon can be absorbed by forests and natural ecosystems.

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SUMMARY The Carbon Cycle and the Oxygen Cycle

- Most of the carbon in living organisms is returned to the atmosphere or water as carbon dioxide when wastes and the bodies of dead organisms decay. Carbon cycles rapidly through the atmosphere or when dissolved in water, but can be held for many years in living things such as trees.
- A tremendous amount of carbon is held in the oceans. Some of the carbon dioxide is dissolved in water, another portion reacts with seawater to form carbonate ions (CO_3^{2-}) and bicarbonate ions (HCO_3^-), and yet another portion is used by algae and plants that perform photosynthesis.
- The largest reservoir for Earth's carbon is in sedimentary rocks, such as limestone ($CaCO_3$), found on the ocean floor and continents.
- Oxygen cycles between living things and the atmosphere via photosynthesis and cellular respiration. Oxygen is stored in the atmosphere, in water, and in rock.
- Humans have modified the global carbon cycle through the increasing use of fossil fuels and by the burning of forests. These cause the release of carbon dioxide at a rate well above natural cycling. In addition, the destruction of vegetation reduces the amount of photosynthesis and thus the volume of carbon dioxide removed from the atmosphere.
- The term albedo is used to describe the extent to which a surface can reflect light that strikes it. The albedo of ice and snow is extremely high, so ice and snow reflect considerable amounts of radiation from the Sun. Changes in Earth's snow and ice cover may affect equilibrium in the biosphere.

EXTENSION

What's Up with the Weather?

FRONTLINE and *NOVA* take on a complex and critical phenomenon—global warming.

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Section 3.2 Questions

1. Explain the importance of decomposers in the carbon cycle.
2. The oceans are often described as a carbon reservoir. In what ways is carbon held within the oceans?
3. Explain how the burning of fossil fuels by humans affects the carbon cycle.
4. Carbon cycles more quickly through some ecosystems than others.
   (a) Explain why carbon is cycled more slowly in northern ecosystems than in the tropics.
   (b) Explain why carbon is cycled more rapidly in grassland communities than in peat bogs and swamps.
5. Study **Table 1**.

Table 1 Carbon Cycle

Carbon movement	Mass of carbon per year (10^{13} kg)
from atmosphere to plants	120
from atmosphere to oceans	107
to atmosphere from oceans	105
to atmosphere from soil	60
to atmosphere from plants	60
to atmosphere from burning of fossil fuels	5
to atmosphere from net burning of plants	2
to oceans from runoff	0.4

   (a) Calculate the amount of carbon entering the atmosphere as carbon dioxide every year and the amount of carbon leaving the atmosphere. Is atmospheric carbon dioxide increasing or decreasing?
   (b) Draw a bar graph showing factors that increase and decrease atmospheric carbon dioxide levels.
   (c) The burning of forests contributes 2×10^{13} kg of carbon yearly, but its impact on creating a carbon imbalance is even greater than the carbon dioxide released from the burning plants. What other factor would be affected by burning forests?
   (d) Provide a list of suggestions that would reduce the flow of carbon dioxide into the atmosphere. How would the suggestions affect your life? Which of your suggestions do you think you could help with?
6. Scientists have expressed concerns about the burning of the rainforests to clear land for farming.
   (a) Explain how the burning of the forests could change oxygen levels in the atmosphere.
   (b) What impact would the change in oxygen levels have on living things?
7. In 1998, the federal government of Canada proposed a "carbon tax" on gasoline.
   (a) Would a carbon tax reduce the amount of carbon dioxide entering the atmosphere? Give reasons for your answer.
   (b) What businesses would be affected by the tax? Explain how they would be affected.
   (c) What other groups or individuals would be affected by the tax? Would it apply equally and fairly to everyone?
   (d) Based on your analysis, who would you expect to oppose the tax? Who would you expect to support the tax?
   (e) What are emission credits and how do these affect the amount of CO_2 produced globally? Do research to find out.

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8. A number of different factors affect the balance of oxygen and carbon dioxide on the planet. Some of these are listed below. Research a factor and draw a poster. Use text to help explain the poster.

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   A. Deforestation means less oxygen is available.
      - Tropical rain forests are being cleared and burned for farming and ranching.
      - Temperate rain forests are being cut for lumber.

   B. Agricultural land is being used for housing developments, new factories, and landfill sites. An overall decrease in plant life will lower oxygen levels.

   C. Increased combustion in factories is increasing the amount of CO_2 in the atmosphere. The increased level of CO_2 elevates temperatures, which;
      - causes the ice caps and glaciers to melt;
      - expands the size of deserts; and
      - changes the types of crops and food supply.
9. As ice and snow cover on Earth decreases, what effect do you think this may have on the equilibrium of Earth's atmosphere?

3.3 The Nitrogen Cycle and the Phosphorus Cycle

Life depends on the cycling of nitrogen. Nitrogen atoms are required so that cells can make proteins. Nitrogen is also required for the synthesis of deoxyribonucleic acid or DNA, the hereditary material found in all living things. The movement of nitrogen through ecosystems, the soil, and the atmosphere is called the **nitrogen cycle**.

nitrogen cycle a cycle of matter in which nitrogen atoms move from nitrogen gas in the atmosphere, to inorganic forms in the soil, to organic forms in living things, and then back to inorganic forms in the soil and nitrogen gas in the atmosphere

When you consider that nitrogen gas (N_2) makes up nearly 79 % of Earth's atmosphere, you would expect nitrogen to be easy for organisms to access. Unfortunately, this is not the case. Nitrogen gas is a very stable molecule, and reacts only under limited conditions. To be useful to plants, nitrogen must be supplied in another form, the nitrate ion (NO_3^-). The nitrogen cycle is exceptionally complex. A simplified description is shown in **Figure 1**.

Nitrogen Fixation

There are two ways in which atmospheric nitrogen can be converted into nitrates, in a process called **nitrogen fixation**. The first method is through lightning, and the second is through bacteria in the soil.

nitrogen fixation two processes in which atmospheric or dissolved nitrogen is converted into nitrate ions

A small amount of nitrogen is fixed into nitrates by lightning. The energy from the lightning causes nitrogen gas to react with oxygen in the air, producing nitrates. The nitrates

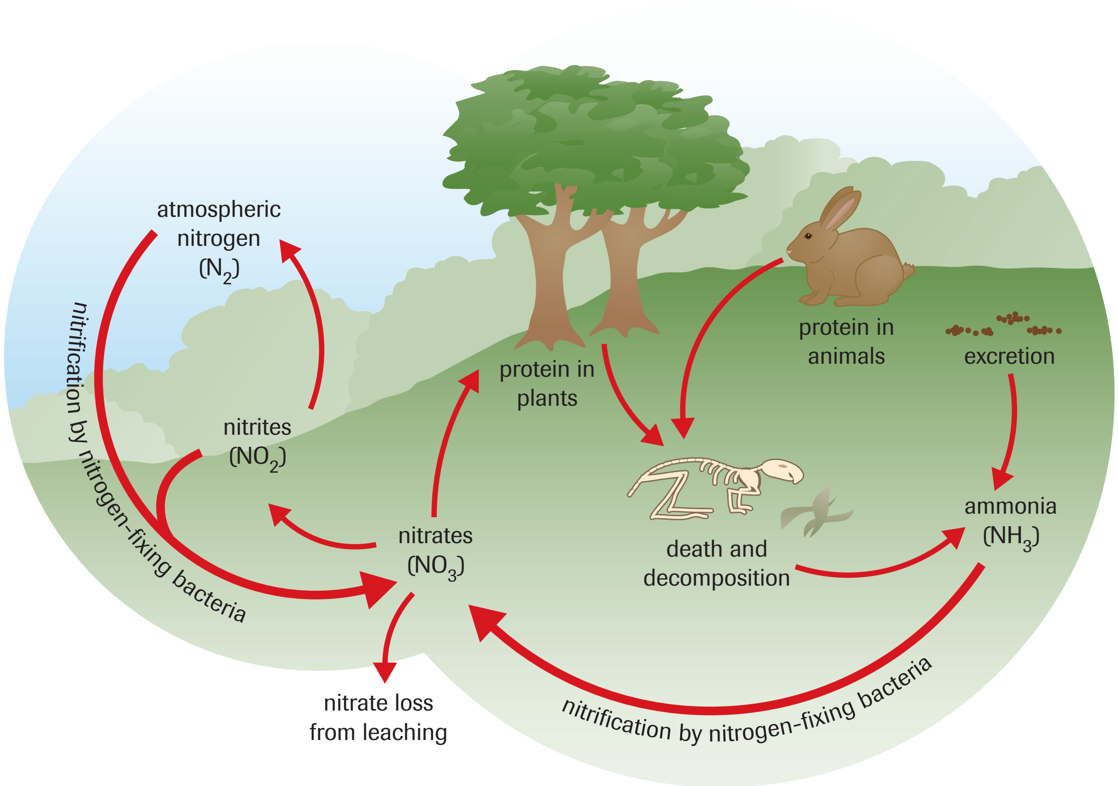

Figure 1

Like carbon, nitrogen moves in a cycle through ecosystems, passing through food chains and from living things to their environment and back again.

dissolve in rain or surface water, enter the soil, and then move into plants through their roots. Plant cells can use nitrates to make DNA, and convert nitrates into amino acids, which they then string together to make proteins. When a plant is consumed by an animal, the animal breaks down the plant proteins into amino acids and then can use the amino acids to make the proteins it needs.

Some bacteria are capable of fixing nitrogen. These bacteria provide the vast majority of nitrates found in ecosystems. They are found mostly in soil. Nitrogen-fixing bacteria can also be found in small lumps called nodules on the roots of legumes such as clover, soybeans, peas, and alfalfa (**Figure 2**). The bacteria provide the plant with a built-in supply of usable nitrogen, while the plant supplies the nitrogen-fixing bacteria with the sugar (energy) they need to make the nitrates. This plant–bacteria combination usually makes much more nitrate than the plant or bacteria need. The excess moves into the soil, providing a source of nitrogen for other plants.

Traditional agricultural practices of including legumes in crop rotation and mixed planting, capitalize on bacterial nitrogen fixation. For example, the Iroquois traditionally planted corn, beans, and squash together. Known as the "Three Sisters," these crops help each other and protect the soil. Corn provides scaffolding for the other plants, while beans add nitrate to the soil. Squash prevents water evaporation and erosion, and helps control the growth of weeds.

Figure 2
A clover root: the swollen nodules contain nitrogen-fixing bacteria

Figure 3
Plants that grow in nitrogen-poor soils can form only a limited amount of chlorophyll. The yellowness of this plant's leaves indicates that the plant is starving for nitrogen.

Nitrogen and Decomposers

All organisms produce wastes and eventually die. When they do, a series of decomposers break down the nitrogen-containing chemicals in the waste or body into simpler chemicals such as ammonia (NH_3). Other bacteria convert ammonia into nitrites, and still others convert the nitrites into nitrates. These bacteria all require oxygen to function. The nitrates, then, continue the cycle when they are absorbed by plant roots and converted into cell proteins and DNA.

Farmers and gardeners who use manure and other decaying matter as fertilizer take advantage of the nitrogen cycle. Soil bacteria convert the decomposing protein in the manure into nitrates. Eventually, the nitrates are absorbed by plants.

Denitrification

At various stages in the decay process, bacteria can break down nitrates into nitrites, and then nitrites into nitrogen gas. Eventually, the nitrogen gas is released back into the atmosphere. This process, called **denitrification**, is carried out by bacteria that do not require oxygen. Denitrification acts to balance nitrates, nitrites, and atmospheric nitrogen in the soil, and completes the nitrogen cycle.

denitrification the process in which nitrates are converted to nitrites and then to nitrogen gas

Older lawns often have many denitrifying bacteria. The fact that denitrifying bacteria grow best where there is no oxygen may help to explain why gardeners often aerate their lawns in early spring. Exposing the denitrifying bacteria to oxygen reduces the breakdown of nitrates into nitrogen gas. Nitrates will then remain in the soil, where they can be drawn in by grass roots and used to make proteins.

This information may also help you understand why the leaves of some plants may not be a rich green colour. Chlorophyll is a protein, and plants require nitrates to make it. The colour of a plant's leaves may tell you the nitrate content of the soil (**Figure 3**).

The denitrification process speeds up when the soil is acidic or water-logged (oxygen content is low). Bogs, for example, are well known for their lack of useful nitrogen. They can support only a few types of plants—those able to live with low levels of nitrogen. Insect-eating plants, such as sundews and pitcher plants (**Figure 4**), are commonly found in bogs. In an interesting reversal of roles, these plants obtain their nitrogen by digesting trapped insects.

Figure 4
Insect-eating plants like this pitcher plant can grow in nitrogen-poor soil.

Agriculture and Nutrient Cycles

The seeds, leaves, flowers, and fruits of plants all contain valuable nutrients, which is why we eat them. However, as crops are harvested, much of the valuable nitrogen and phosphorus in these plants is removed and does not return to the field or orchard. This diversion of nitrates and phosphate from the local cycles would soon deplete the soil unless the farmer replaced the missing nutrients. **Fertilizers** are materials used to restore nutrients and increase production from land. Some estimates suggest that fertilizers containing nitrogen and phosphates can double yields of cereal crops such as wheat and barley. However, fertilizers must be used responsibly. More is not necessarily better.

fertilizer a material used to restore nutrients to plants

Soil bacteria convert the nitrogen content of fertilizers into nitrates, but the presence of high levels of nitrates may result in an increase in the amount of nitric acids in the soil. Changes in the levels of acidity can affect all organisms living in the soil, including decomposer bacteria.

Depending on the soil and the other chemicals in the fertilizer, a typical annual application of between 6 and 9 kg/ha of nitrogen fertilizer can, in 10 years, produce a soil that is 10 times more acidic. This can have devastating effects on food production. Most grassland soils in Canada's prairies have a pH near 7 (neutral). If the soil becomes more acidic, some sensitive crops like alfalfa and barley will not grow as well. Acid rain and snow only add to the problem.

Fertilizer and Ecosystems

The accumulation of nitrogen and phosphate fertilizers produces an environmental problem. As spring runoff carries decaying plant matter and fertilizer-rich soil to streams and then lakes, the nutrients allow algae in the water to grow more rapidly (**Figure 5**) in what is called an algal bloom. When the algae die, bacteria use oxygen from the water to decompose them. Because decomposers flourish in an environment with such an abundant food source, oxygen levels in lakes drop quickly, so fish and other animals may begin to die. Dying animals only make the problem worse, as decomposers begin to recycle the matter from the dead fish, allowing the populations of bacteria to grow even larger, and use still more oxygen.

Figure 5
Spring runoff of nitrogen and phosphorus fertilizers promotes the growth of algae.

Nitrates present another problem. As you have seen, there are bacteria that convert nitrates into nitrites (NO_2^-). But nitrites are dangerous to animals that have hemoglobin in their blood, such as humans and other mammals, fish, reptiles, and amphibians. Nitrites can attach to the hemoglobin in blood, reducing its ability to carry oxygen to tissues.

The problem of nitrates in drinking water is especially serious for young animals, including human infants. Humans and other animals usually have bacteria that convert nitrates into nitrites in their large intestines. For adults, the presence of these bacteria in the digestive system is not harmful, because the stomach of an adult is so acidic that the bacteria cannot survive. But the stomach of an infant is much less acidic, so the bacteria can move up into the stomach, where they will convert nitrates into nitrites. The nitrites can then pass into the blood of the infant.

The question of how much nitrate should be allowed in drinking water and food is important, but we also need to know more about the nitrogen cycle in order to properly evaluate the environmental impact of nitrates.

mini Investigation — Effects of Nitrogen on Algal Growth

Spring runoff of nitrogen fertilizers causes algae to grow rapidly in neighbouring lakes. In some lakes, a film of algae coats the entire surface of the water. This makes the lake a lot less appealing to swim in. More importantly, the resulting lack of oxygen places other organisms in the ecosystem in peril.

By passing pond water through a filter and then allowing the filter and algae to dry, you can measure the mass of algae collected.

(a) Using this technique, design a controlled investigation to measure how a fertilizer affects growth of algae.

- Have your design, safety precautions, materials, and written procedure approved by your teacher before beginning the procedure. Conduct your investigation and collect your results.

(b) Report on the results of your investigation. Include an evaluation of your design, as well as suggestions for improvement.

The Phosphorus Cycle

Phosphorus is a key element in cell membranes, in molecules that help release chemical energy, in the making of DNA, and in the calcium phosphate of bones. The **phosphorus cycle** has two parts: a long-term cycle involving the rocks of Earth's crust, and a short-term cycle involving living organisms (**Figure 6**).

phosphorus cycle the cycling of phosphorus between the biotic and abiotic components of the environment; consists of a biological and geochemical cycle

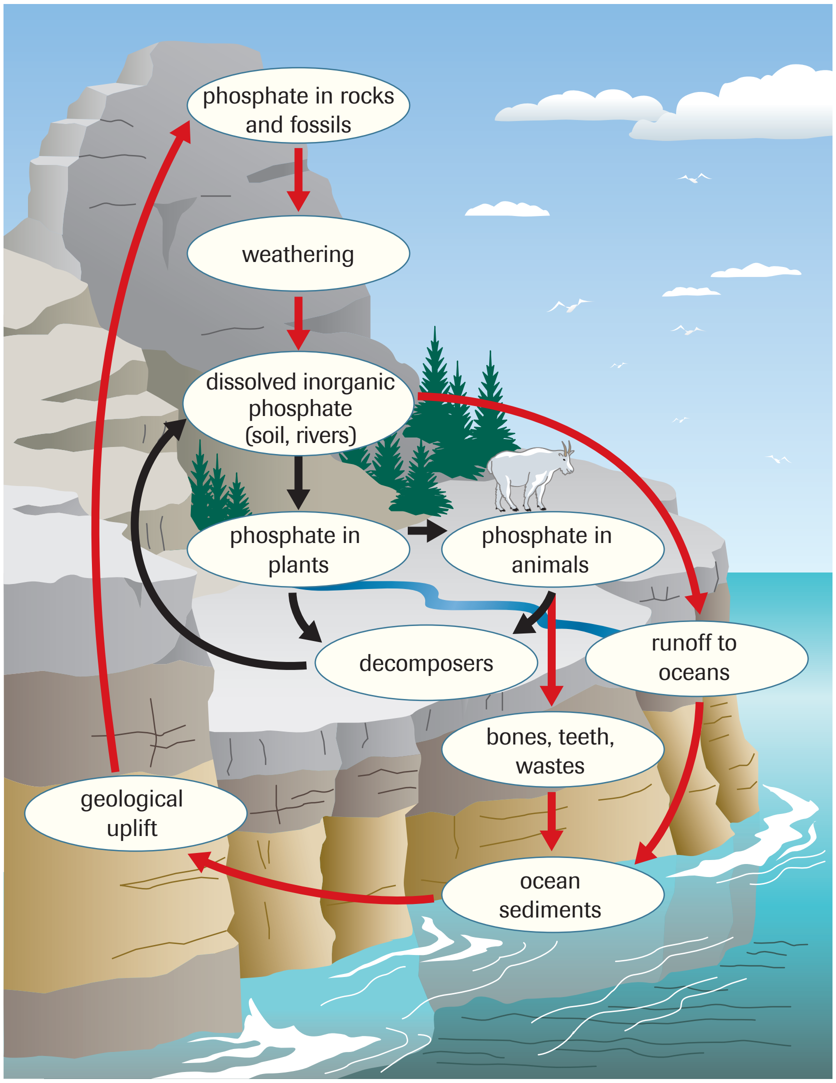

Figure 6 Phosphates cycle in both long (red arrows) and short (black arrows) cycles.

DID YOU KNOW?

Matter Cycling in a Closed System

In the International Space Station, carbon dioxide, oxygen, water, and other materials must be recycled. How does matter cycling work in a closed system? Research the life support systems of the ISS to answer this question.

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Living things divert phosphates from the normal (long) rock cycle. Phosphorus is found in bedrock in the form of phosphate ions (PO_4^{3-}), combined with a variety of elements. Phosphates are soluble in water and so can be dissolved out of rock. While dissolved, phosphates can be absorbed by photosynthetic organisms and so pass into food chains.

Phosphates eroded from rock are also carried by water from the land to rivers, and then to the oceans. In the ocean, phosphates are absorbed by algae and other plants, where they can enter food chains. Marine animals use phosphates to make bones and shells. When they die, these hard remains form deposits on the ocean floor. Covered with sediment, the deposits eventually become rock, ready to be brought to the surface again. The long cycle can take millions of years to complete.

In the short cycle, wastes from living things are recycled by decomposers, which break down wastes and dead tissue and release the phosphates. The short cycle is much more rapid.

Variations in Nutrient Cycling

nutrient a chemical that is essential to living things

Nitrates and phosphates are both nutrients. **Nutrients** are chemicals that are essential to living things. Potassium, calcium, and magnesium are other examples of nutrients. The rate at which nutrients cycle through an ecosystem is linked to the rate of decomposition. Organic matter decomposes relatively quickly in the tropical rain forests. Warmth, moist soil, and the vast number of diverse and specialized decomposers permit a cycle to be complete in as little as a few months. Cycling in cooler forests takes an average of between four and six years. In the even cooler tundra, nutrient cycling takes up to 50 years. In the oxygen-poor environment of most lakes, cycling may take even longer. Temperature and oxygen levels are the two most important abiotic factors regulating decomposition. Other factors, such as soil chemistry and the frequency of fire, also affect decomposition and cycling.

INVESTIGATION 3.4 ***Introduction***

Phosphate Identification

Phosphate is a common pollutant that may arise from human activity. The presence of phosphates in water can be detected by adding magnesium sulfate. In this investigation, you will use this salt to test various water samples for the presence of this pollutant.

Report Checklist

- ○ Purpose
- ○ Problem
- ○ Hypothesis
- ○ Prediction
- ○ Design
- ○ Materials
- ○ Procedure
- ● Evidence
- ● Analysis
- ● Evaluation
- ● Synthesis

To perform this investigation, turn to page 71.

WEB Activity

Case Study—Persistent Pesticides and Matter Flow

Pesticides are chemicals designed to kill pests. A pest is an organism that people consider harmful or inconvenient, such as weeds, insects, fungi, and rodents. In many situations, pesticides are used to protect species that are beneficial to humans from a competitor or predator that is less useful. One estimate suggests that as much as 30 % of the annual crop in Canada is lost to pests such as weeds, rusts and moulds (both forms of fungi), insects, birds, and small mammals. The cost to consumers can be staggering. For example, in 1954 three million tonnes of wheat from the Prairies was destroyed by stem rust, a fungus that grows inside the leaves and stems of the wheat and other plants, feeding on the plant's stores of food.

In 1998, a total of 9 300 497 kg of pesticides were sold in, or shipped into, Alberta. By far the greatest amount, approximately 96 %, can be linked to agriculture. Persistent pesticides are those that break down very slowly, and so affect the environment for a long period. This activity is a case study of the use of persistent pesticides in Alberta and other regions.

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SUMMARY — The Nitrogen Cycle and the Phosphorus Cycle

- Life depends on the cycling of nitrogen, which is required for the synthesis of proteins and DNA. The movement of nitrogen through ecosystems, the soil, and the atmosphere is called the nitrogen cycle.
  - Atmospheric nitrogen is converted into nitrates by nitrogen fixation, either by lightning or by bacteria in the roots of legumes.
  - Decomposers break down nitrogen compounds in wastes or dead bodies into simpler compounds such as ammonia (NH_3). Other bacteria convert ammonia into nitrites, and still others convert the nitrites back into nitrates.
  - Denitrifying bacteria break down nitrates into nitrites, and then nitrites into nitrogen gas, which is released back into the atmosphere.
- Phosphorus is found in cell membranes, in energy-containing molecules, in DNA, and in bones.
- Phosphorus cycles in two ways: a long-term cycle involving the rocks of Earth's crust, and a short-term cycle involving living organisms.
- The rate of cycling of nutrients is linked to the rate of decomposition.

Section 3.3 Questions

1. Why do the levels of nitrogen and phosphorus in fields decline when crops are harvested?
2. Explain how excess fertilizers might affect decomposing organisms.
3. (a) Why do algal blooms usually occur in spring?
   (b) Explain how algal blooms affect other organisms in freshwater ecosystems.
4. What dangers do high levels of nitrates in the drinking water present for infants?
5. If a farmer does not plant a crop in one field, and then plows the field in the fall, how would this help restore nitrogen and phosphorus levels in the soil?
6. Explain why nitrogen is important to organisms.
7. If nearly 79 % of the atmosphere is nitrogen, how could there be a shortage of nitrogen in some soils?
8. How do animals obtain usable nitrogen?
9. Nitrogen-fixing bacteria are found in the roots of bean plants. Explain how the bacteria benefit the plant and how the plant benefits the bacteria.
10. Draw a diagram of the nitrogen cycle for a farm or garden where manure is used.
11. Explain why it is a good practice to aerate lawns.
12. Explain why phosphorus is important to living things.
13. Some farmers alternate crops that require rich supplies of nitrogen, such as corn, with alfalfa. Alfalfa is usually less valuable in the marketplace than corn. Why would farmers plant a crop that provides less economic value?
14. Explain why bogs and swamps are usually low in nitrogen.
15. Speculate about why clover would begin to grow in an older lawn. How would the presence of clover benefit the lawn?
16. Nitrate levels were analyzed from living material and soil samples in three different ecosystems (grassland, temperate rain forest, and tropical rain forest) in the same month. To determine the mass of nitrates in living things, all living plant matter was collected in a study area and the levels of nitrates were determined. The same analysis was conducted for the top layer of soil. The results are listed in **Table 1**, where each ecosystem is identified by a number.

Table 1 Nitrate Content of Three Ecosystems

Study area	Soil nitrates (kg/ha)	Biomass nitrates (kg/ha)	Soil temperature (°C)
1	30	90	25
2	10	175	19
3	2	270	30
tundra	?	?	?

   (a) In which community does nitrogen cycle most rapidly? Explain your conclusion.
   (b) Which ecosystem (grassland, temperate rain forest, and tropical rain forest) is study area 1, 2, and 3? Give reasons for your answers.
   (c) Speculate about the data that might be collected from a tundra ecosystem. Explain your prediction.
17. The phosphorus cycle has been described as having two components—a long cycle and a short cycle. The carbon cycle can be described the same way. Draw a diagram that splits the carbon cycle into “short” and “long”components.
18. Human waste contains nitrates and nitrites. Before the arrival of municipal sewers, the backyard outhouse was standard for collection of human waste. Outhouses can still be found at some cottages. Outhouses consist of a small building over a hole in the ground. Explain why outhouses pose a risk to neighbouring lakes, using information that you have gained about the nitrogen cycle.
19. How is the water cycle important in the cycling of nitrogen and phosphorus?
20. The use of nitrogen-rich fertilizers has allowed farmers to abandon crop rotation.
   (a) What advantages are gained from planting wheat year after year?
   (b) New strains of crops have been especially bred to take up high levels of nitrogen. These strains produce more grain. Speculate about some possible long-term disadvantages that these crops might present for ecosystems.
21. People have used fertilizers for a long time. Explain why we must begin changing our views on the use of fertilizers so the ecosystems we live in will be sustainable. Why is it so difficult to change practices?
22. Crop rotation is an effective way of restoring nitrogen to the soil; however, the planting of legumes is not always popular with farmers. Legume crops may provide less income, because they are more costly to plant, difficult to tend and harvest, and worth less in the marketplace. Farmers must continually balance short-term gains and long-term results in this way. Provide some examples of how you balance short-term gains with long-term results in decisions that you make.

INVESTIGATION 3.1

Nutrient Cycling and Plant Growth

In a natural setting, plants grow without benefit of artificial fertilizers. The continuous recycling of nutrients between decomposing matter and growing plants, together with changes in the species of plants growing in the soil, ensures that the soil remains productive. However, not all soils are equal. In this investigation, you will determine whether nutrients leached from different soils can promote plant growth. Since many of these nutrients are water-soluble, they are carried downward to the lower levels of the soil by percolation.

Report Checklist

- ○ Purpose
- ● Problem
- ○ Hypothesis
- ○ Prediction
- ● Design
- ○ Materials
- ○ Procedure
- ● Evidence
- ● Analysis
- ● Evaluation
- ● Synthesis

Design

This is a controlled experiment to determine which of three soil samples yields the most dissolved nutrients. Seeds are planted in standard potting soil and watered using leachate from three soil samples.

(a) Identify the dependent and independent variables in this experiment.

(b) What control is used in the experiment? Explain your answer.

Materials

safety goggles
apron
250 mL clay soil (sample A)
250 mL silt soil (sample B)
250 mL sandy soil (sample C)
soil-less potting mixture such as vermiculite
food colander
cheesecloth
distilled water
250 mL beaker
bucket or other large container
3 plastic storage bottles
marking pen
pots or other containers
pea, corn, or bean seeds (presoaked for 24 h)
100 mL graduated cylinder

CAUTION: Always wash your hands thoroughly after handling soil.

Procedure

1. Line a colander with cheesecloth. Place 250 mL of soil sample A in the colander. Position a large container under the colander and pour 250 mL of distilled water over the soil (**Figure 1**). Allow the water to collect in the container.

Figure 1

2. Repeat step 1 twice, reusing the water in the container. After the final filtering, pour the filtered water into a plastic storage bottle and label it "leachate from soil sample A."
3. Repeat steps 1 and 2 for soil samples B and C, using clean cheesecloth and fresh water .
4. Pour a 20-cm depth of soil-less potting mixture into each of four plant pots. Label the pots A, B, C, and control.
5. Plant five seeds in each pot.
6. Using a 100 mL graduated cylinder, add 50 mL of leachate from soil sample A to the pot labelled A, from soil sample B to pot B, and from soil sample C to pot C.
7. Add 50 mL of distilled water to the seeds in the pot labelled "control."
8. Put the pots in a warm, well-lit location.
9. Each day, check the pots for moisture (they should be moist, but not wet). If water must be added, add the same amount of water to each pot from its leachate bottle.

INVESTIGATION 3.1 *continued*

Evidence

(c) Record the height of each plant every day. Make notes on the colour, health, and appearance of each of the plants.

Analysis and Evaluation

(d) Calculate the mean height for the control and experimental plants each day. (If one seed in a group fails to germinate and grow, do not count it when you calculate the mean).

(e) Why is it useful to report the mean height for all five plants, rather than the height of each individual plant?

(f) Plot a line graph of the mean height over time for the control and experimental groups.

(g) Read the comments you kept about the plants as they grew and review your growth data. Does the evidence that you collected in this experiment support or contradict your prediction? Explain your answer.

Synthesis

(h) Grain farmers may burn the stubble (the stalks of the grain plants) after harvest. List the advantages and disadvantages of burning stubble for
 (i) the farmer
 (ii) soil organisms
 (iii) neighbours

(i) Suggest gardening techniques that could help reduce the amount of artificial fertilizer used in a garden.

INVESTIGATION 3.2

Report Checklist

○ Purpose	○ Design	● Analysis
● Problem	○ Materials	● Evaluation
○ Hypothesis	○ Procedure	● Synthesis
● Prediction	● Evidence	

The Albedo Effect

Purpose

To examine the ability of selected colours and surface conditions to reflect light

Materials

desk lamp	dissecting pan
ring stand	sand
extension clamp	gravel
light sensor	soil
coloured card stock (including black and white)	water
	snow and/or ice

Procedure

1. Aim the desk lamp at the bench surface.
2. Attach the light sensor to the ring stand so that it is higher than the light source. Its active surface must face down and have a clear path to the surface of the bench. (**Figure 1**).
3. Place the sheet of white card stock directly under the lamp.

Figure 1
The experimental setup

INVESTIGATION 3.2 *continued*

Evidence

4. Turn on the lamp and record the reading from the light sensor.
5. Repeat the experiment, using the other coloured sheets. Remember to control all your variables.
6. Set the dissecting pan directly under the lamp.
7. Record the reflective value of the pan when empty. Repeat, using a sand surface, a gravel surface, soil, water, and snow and ice.

Analysis and Evaluation

(a) Why is it necessary to keep the light sensor out of the direct line of light?

(b) What variable must be controlled?

(c) Why are black and white card stock colours used in this experiment?

(d) List the coloured surfaces in order from least to greatest reflected light.

(e) Use your data to make comments on the albedo effect of the materials used.

(f) What variable were you unable to control in Step 7 of the laboratory procedure? How could you redesign these steps to account for the variable?

(g) Design an experiment to measure the effect of colour or surface conditions on the absorption of heat. State your hypothesis and the predictions resulting from it.

(h) Perform the investigation you designed (approval of instructor required) and draw conclusions based on the collected data.

Synthesis

(i) In order to melt a pile of snow more quickly, a researcher sprayed dye-coloured water on it. Which colour was probably selected and why?

INVESTIGATION 3.3

Environmental Models

Report Checklist

○ Purpose	● Design	● Analysis
● Problem	○ Materials	● Evaluation
● Hypothesis	● Procedure	○ Synthesis
● Prediction	● Evidence	

Environmental models allow scientists to study what could happen in an ecosystem if changes occurred. Models help check predictions without disrupting a large area. In this investigation, you will build an ecocolumn, an ecological model that is especially designed to cycle nutrients. You will then design and carry out an experiment to investigate one of three environmental problems.

Problem

(a) Choose from one of the three ecological problems below:

A. How would an oil spill affect an aquatic ecosystem? (You will be allowed to use motor oil to test the environmental impact.)

B. How would acid rain affect an ecosystem? (You will be allowed to use household vinegar only.)

C. How would rapid changes in climate affect an ecosystem?

(b) Research the problem and provide at least one page explaining the environmental problem.

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Prediction

(c) Make a prediction.

Design

(d) Based on the materials and instructions below for building an ecocolumn, design your experiment. Include materials, a procedure, and any needed safety precautions. Present your design for approval before beginning.

INVESTIGATION 3.3 *continued*

Materials

2 or more 2 L plastic pop bottles with caps (remove labels)
pond water, soil compost
representative organisms (moss, flies, spiders, snails, etc.)
scissors
duct tape or binding tape (wide width) or silicone sealant

Instructions for Building the Ecocolumn

1. Using scissors, remove the top and bottom of a 2-L plastic bottle, as shown in **Figure 1.**
2. Cut a second bottle just before the point at which the bottle narrows (**Figure 2**).

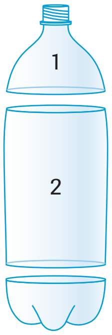

Figure 1

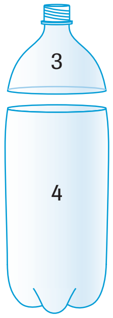

Figure 2

3. Slide part 1 into part 2, as shown in **Figure 3**. Seal the two together with silicone or tape. Next stack the structure on top of part 4.
4. A example of a more complex ecocolumn is shown in **Figure 4**. You decide on the design.

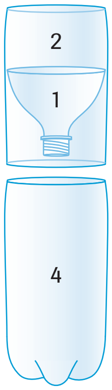

Figure 3

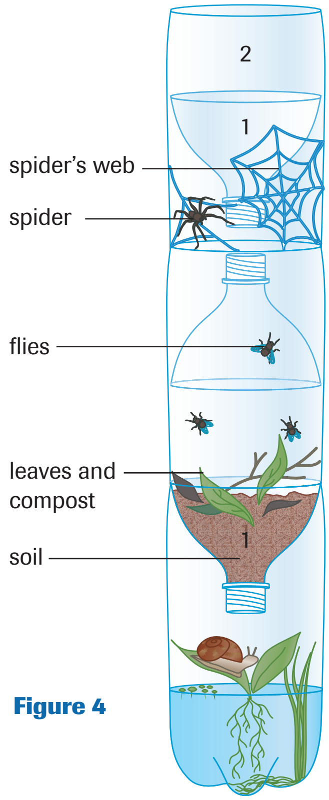

Figure 4

INVESTIGATION 3.4

Phosphate Identification

Algae populations increase rapidly in response to phosphate pollution. There is a quick, simple test for detecting this form of pollution. The presence of phosphates in a water sample can be detected by adding the salt magnesium sulfate. The magnesium in the compound combines with phosphates in the water to form the insoluble salt magnesium phosphate. As crystals of magnesium phosphate form, they turn the clear solution in the test tube cloudy.

Wear gloves throughout the procedure, and wash your hands thoroughly.

Report Checklist

○ Purpose	○ Design	● Analysis
○ Problem	○ Materials	● Evaluation
○ Hypothesis	○ Procedure	● Synthesis
○ Prediction	● Evidence	

Materials

goggles
safety gloves
apron
4 large test tubes
test-tube rack
waterproof marker
distilled water (A)
water samples from your local area (B, C, and D)
10 mL graduated cylinder
medicine dropper
dilute ammonium hydroxide solution
magnesium sulfate solution
watch glass
hand lens
pH paper, pH probe, or pH meter

Procedure

1. Obtain four large test tubes and label them A, B, C, and D. Place the tubes in a test-tube rack. Using a graduated cylinder, pour 10 mL of distilled water into tube A. Pour 10 mL each of samples B, C, and D into the test tube with the corresponding letter label. Rinse and dry the cylinder after each sample.
2. Measure and record the pH of each sample.
3. Using a medicine dropper, add 25 drops of dilute ammonium hydroxide to each sample. This will ensure that the samples will be basic (have a pH greater than 7).
4. Using the graduated cylinder, add 2 mL of magnesium sulfate solution to each of the samples in the test tubes. Let the test tubes stand for 5 min. Record your observations over the 5 min.
5. Pour a small sample of the solution from test tube A into a clean watch glass. Using a hand lens, examine the sample for crystals. Record your observations. Repeat this step for each of the other samples.
6. Wash your hands, first with your gloves on and then without.

Analysis and Evaluation

(a) Based on your results, which of the samples contained phosphates?

(b) Speculate about the source of phosphates in each of the samples that tested positive. What is the most likely source? Make a plan to determine the source of the phosphates.

(c) Was pH related to the amount of phosphate in the samples? Explain.

Synthesis

(d) The pH of lakes and streams can change as a result of acid rain. Predict how acidification of a lake would affect its phosphate levels.

(e) Predict how lake acidification would affect the biomass of a lake ecosystem. Explain your reasoning, using a food chain or food web.

Chapter 3 SUMMARY

Outcomes

Knowledge

- explain and summarize the cycling of carbon, oxygen, nitrogen, and phosphorus, and relate to reuse of all matter in the biosphere (3.2, 3.3)
- explain water's role in the matter cycles, using its chemical and physical properties (3.1)
- explain how the equilibrium between gas exchanges in photosynthesis and cellular respiration influences atmospheric composition (3.2)
- describe the geological evidence (stromatolites) and scientific explanations for change in atmospheric composition, with respect to O_2 and CO_2, and the significance to current biosphere equilibrium (3.2)

STS

- explain that science and technology are developed to meet societal needs and expand human capabilities (all)
- explain that science and technology have both intended and unintended consequences for humans and the environment (all)

Skills

- ask questions and plan investigations by: designing an experiment to compare the carbon dioxide production of plants with that of animals (3.2); hypothesizing how alterations in the carbon cycle as a result of the burning of fossil fuels might interact with other cycling phenomena (3.2); predicting disruptions in the nitrogen and phosphorus cycles that are caused by human activities (3.1, 3.3); and predicting the effects of changes in carbon dioxide and oxygen concentration due to factors such as a significant reduction of photosynthetic organisms, combustion of fossil fuels, agricultural practices (3.2)
- conduct investigations and gather and record data and information by measuring and recording the pH and the amount of nitrates, phosphates, iron or sulfites in water samples within the local area (3.3)
- analyze data and apply mathematical and conceptual models by: analyzing data collected on water consumption and loss in plants and animals (3.1); and designing and evaluating a model of a closed biological system in equilibrium with respect to carbon dioxide, water, and oxygen exchange (3.2)
- work as members of a team and apply the skills and conventions of science (all)

Key Terms

3.1

polar molecule
hydrogen bond
hydrological cycle (water cycle)
transpiration
percolation
water table
leaching

3.2

carbon cycle
combustion
peat
albedo
stromatolite

3.3

nitrogen cycle
nitrogen fixation
denitrification
fertilizer
phosphorus cycle
nutrient

MAKE a summary

1. Draw a diagram of a terrestrial or an aquatic ecosystem that shows how matter is cycled. Pay particular attention to the carbon and nitrogen cycles.
2. Revisit your answers to the Starting Points questions at the start of the chapter. Would you answer the questions differently now? Why?

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The following components are available on the Nelson Web site. Follow the links for *Nelson Biology Alberta 20–30*.

- an interactive Self Quiz for Chapter 3
- additional Diploma Exam-style Review Questions
- Illustrated Glossary
- additional IB-related material

There is more information on the Web site wherever you see the Go icon in the chapter.

UNIT 20 A PERFORMANCE TASK

Environmental Effects of Human Communities

In this Performance Task, you will use the knowledge and skills you gained in this Unit to study the impact of humans on natural ecosystems. You will choose one of the following tasks: (1) design a golf course; (2) assess community water quality; or (3) design a game that teaches about the effects of human activities on the environment. Go to the Unit 20 A Performance Task link on the Nelson Web site to complete the task.

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Chapter 3 REVIEW

Many of these questions are in the style of the Diploma Exam. You will find guidance for writing Diploma Exams in Appendix A5. Science Directing Words used in Diploma Exams are in bold type. Exam study tips and test-taking suggestions are on the Nelson Web site.

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DO NOT WRITE IN THIS TEXTBOOK.

Part 1

1. Which statements accurately describe photosynthesis and cellular respiration?
   A. Photosynthesis is carried out by plants and animals and uses glucose as the energy source. Cellular respiration is carred out by plants only and uses solar energy as the energy source.
   B. Photosynthesis is carried out by plants only and uses glucose as the energy source. Cellular respiration is carred out by plants and animals and uses solar energy as the energy source.
   C. Photosynthesis is carried out by plants only and uses solar energy as the energy source. Cellular respiration is carred out by plants and animals and uses glucose as the energy source.
   D. Photosynthesis is carried out by plants and animals and uses solar energy as the energy source. Cellular respiration is carred out only by plants and uses carbon dioxide as the energy source.

2. At various stages in the decay process, bacteria can break down nitrates to nitrites, and then nitrites to (1) _________. The process called (2) _________ releases nitrogen gas back into the atmosphere.
   A. (1) nitrate, (2) denitrification
   B. (1) nitrogen gas, (2) denitrification
   C. (1) nitrate, (2) nitrogen fixation
   D. (1) nitrogen gas, (2) nitrogen fixation

3. The term *albedo* is used to describe the extent to which a material can reflect sunlight. Which substance has the highest albedo?
   A. Dark soil: It absorbs sunlight, which warms the surface of the biosphere and stimulates plant growth.
   B. Water: It holds the heat from solar energy and serves as a heat source for the land.
   C. Snow: It is a contributing factor to low temperatures experienced during winter. It also delays spring, even though there is more solar radiation available per unit area.
   D. Clouds: They ensure that less incoming radiant energy is reflected directly back into space. Clouds decrease solar radiation, thereby increasing the warming of the air, which in turn decreases plant growth.

Use the following information to answer questions 4 and 5.

Four different soil samples with varying amounts of water were used to measure the conversion of ammonia to nitrates. The results are shown in **Figure 1**. The coloured lines show the percent of ammonia in each soil sample that was converted to nitrates. The labels for each line give the percent of water present in the sample.

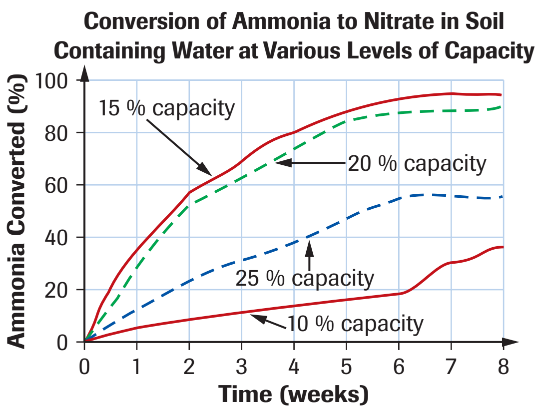

Figure 1

4. According to the data presented, the amount of ammonia converted to nitrates after 4 weeks would be approximately
   A. 80 % in the soil sample that contained 15 % of its water capacity.
   B. 80 % in the soil sample that contained 10 % of its water capacity.
   C. 20 % in the soil sample that contained 20 % of its water capacity.
   D. 20 % in the soil sample that contained 25 % of its water capacity.

5. According to the data presented, the best amount of water within the soils for conversion of ammonia to nitrates is
   A. 10 % capacity
   B. 15 % capacity
   C. 20 % capacity
   D. 25 % capacity

Part 2

6. **Describe** two ways in which the carbon cycle and oxygen cycle are connected.
7. In your own words, **define** *matter cycle*.
8. In your own words, **define** *biomass*.

Use the following information to answer questions 9 to 12.

Figure 2 is a diagram of an ecosystem.

Figure 2

9. Using the organisms in the ecosystem, **explain** the carbon cycle.
DE

10. **Sketch** a flow chart that shows how nitrogen in the air reaches the caterpillar.
DE

11. **Figure 2** doesn't show any bacteria, but they are always present in ecosystems. **Identify** the roles that bacteria have in the ecosystem.
DE

12. **Identify** the organism that would end up with the highest concentration of the insecticide in its body, if DDT were used to control mosquitoes in the ecosystem. **Justify** your choice.
DE

13. (a) In your own words, **define** *nutrient*.
(b) **Why** do nutrients cycle faster in a tropical rainforest than in the tundra?

14. In your own words, **define**
(a) nitrogen fixation
(b) denitrification

15. Nitrogen is cycling through the ecosystems near your home and school. Choose a local natural wooded area and **sketch** a diagram to show how nitrogen cycles within this area.

Use the following information to answer questions 16 to 20.

A researcher carried out an experiment in a deciduous forest near Rocky Mountain House to determine the rate of decay of fallen leaves. At three times during a year, all the dead leaves were collected from 100 1 m^2 plots on the ground. The leaves were sorted by species, and the dry mass of each species' leaves was recorded. Data is provided in **Table 2**. In the table, the numbers in brackets indicate the percentage of the mass of the leaves of each species remaining.

Table 2 Leaves in a Deciduous Forest

Type of leaf	Dry mass (g) and percentage (%) of mass remaining		
	Nov.	**May**	**Aug.**
aspen poplar	4200 g (100 %)	2422 g (58 %)	1100 g (26 %)
balsam poplar	3700 g (100 %)	3110 g (89 %)	1540 g (42 %)
willow	2980 g (100 %)	1001 g (34 %)	6 g (<1 %)
birch	5700 g (100 %)	3987 g	1121 g

16. **Determine** the percentage of the dry mass remaining of the birch leaves in May and August.
DE

17. **Identify** the species that decays fastest between November and May.
DE

18. **Identify** the species that decays fastest between May and August.
DE

19. **Infer** the abiotic factor(s) that could accelerate the amount of decay between November and May and between May and August.
DE

20. **Infer** the biotic factor(s) that could accelerate the amount of decay between November and May and between May and August.
DE

21. **Why** do farmers add nitrogen fertilizers but not carbon fertilizers to fields?

22. **Explain** why every ecosystem must have some continuous supply of energy to survive but can do quite well without a continuous influx of nutrients.

Use the following information to answer questions 23 to 26.

An experiment studied the effects of various factors on photosynthesis. *Elodea,* a water plant, was placed in a test tube of water. The test tube was supported upright on a stand and a light was shone at the side of the test tube. The number of oxygen bubbles produced by the plant was counted for 5 min. **Table 3** shows the collected data.

Part 1: Distance of the light source: The light source was placed 5 cm and 20 cm away from the *Elodea*. Data was collected for two trials for each distance.

Part 2: Sodium bicarbonate added: A small amount of sodium bicarbonate ($NaHCO_3$) was added to the test tube. Data was collected for two trials with the lamp 5 cm from the test tube.

Table 3 Data from *Elodea* Experiment

Experimental condition	Number of oxygen bubbles produced in 5 min		
	Trial 1	Trial 2	Average
lamp 5 cm from plant	50	62	56
lamp 20 cm from plant	27	24	25.5
plant in $NaHCO_3$, lamp 5 cm away	78	84	81

23. DE Write a hypothesis for Part 1 of the experiment.

24. DE **Identify** the manipulated (independent) variable and responding (dependent) variable in Part 1.

25. DE **Identify** variables that must be controlled in Part 1.

26. DE Sodium bicarbonate undergoes the following reaction in water. **Explain** the results obtained from Part 2 of the experiment.

$$2\ NaHCO_3(aq) \rightarrow Na_2CO_3(aq) + CO_2(g) + H_2O(l)$$

27. A forest fire destroyed a 25 ha forest in the Swan Hills area of northwestern Alberta. Years after the fire, the forest had been regrown. A field biologist noted that pine and spruce trees in the area that had been burned appeared more lush than trees in forest areas that had not been affected by the fire. **How** is it possible that the vegetation appeared more lush in the area that had been burned?

28. Fire is a decomposer. It turns complex organic molecules into inorganic nutrients. Fire can be used to release inorganic nutrients from the stalks remaining after grain is harvested. This process is faster than normal decomposition, but much of the carbon in the stalks escapes to the air as carbon dioxide. Should fire be used to return nutrients to the soil? **Criticize** this position. Include both benefits and risks in your answer.

29. (a) **Describe** some of the ways oxygen cycles through the biosphere?
    (b) **Sketch** your own diagram of the oxygen cycle.

30. **How** might changes in the carbon cycle, due to burning fossil fuels, affect the cycling of water in the biosphere?

Use the following information to answer questions 31 to 35.

Under controlled laboratory conditions, a research team from Environment Alberta monitored the solubility of oxygen and carbon dioxide in water samples taken from Lake Wabamun. Their data are shown in **Table 4**.

Table 4 Changes in Solubility of Carbon Dioxide and Oxygen with Temperature

Temp (°C)	CO_2 solubility (ppm)	O_2 solubility (ppm)
0	1.00	14.6
5	0.83	12.7
10	0.70	11.3
15	0.59	10.1
20	0.51	9.1
25	0.43	8.3
30	0.38	7.5

31. DE **Sketch** a graph of the solubility of oxygen in the water.

32. DE **Relate** oxygen solubility in water to temperature.

33. DE Using the data collected by the researchers, **predict** the consequences of prolonged warming of a shallow lake.

34. DE Using the data from the table, **explain** why carbon dioxide levels can become dangerously high in an Alberta lake in winter.

35. DE **Explain** why solubility of oxygen in water is so much greater than that for carbon dioxide at all temperatures.

36. The albedo of the planet Venus is very high. At the same time, the atmosphere of the planet has an exceptionally high concentration of greenhouse gases. **How** might these two factors affect the surface temperature of Venus?

37. A plowed field is adjacent to the fairway of a golf course. During the winter, equal depths of snow cover the field and the fairway. Assuming that both fields are level and there is no disturbance to the snow pack, **explain** why the plowed field loses most of its snow before the fairway even begins to lose its cover. Is there a danger associated with the early loss of snow cover on the plowed field?

38. In this chapter, you have studied the cycling of carbon, oxygen, nitrogen, and phosphorus. In one or two paragraphs, **explain** how each cycle is part of the general reuse of all matter in the biosphere.

Many of these questions are in the style of the Diploma Exam. You will find guidance for writing Diploma Exams in Appendix A5. Science Directing Words used in Diploma Exams are in bold type. Exam study tips and test-taking suggestions are on the Nelson Web site.

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DO NOT WRITE IN THIS TEXTBOOK.

Part 1

1. Place the following organisms in order as they would be in a food chain. (Record all four digits of your answer.)
NR
1. salmon
2. shark
3. plankton
4. small herring

2. Place the following levels in order, from the level with the most energy available to the level with the least energy available. (Record all four digits of your answer.)
NR
1. tertiary consumers
2. producers
3. secondary consumers
4. primary consumers

3. In a food web, organisms that break down organic matter, returning nutrients to the ecosystem for further growth, can be classified as _____.
A. herbivores
B. omnivores
C. detritus
D. decomposers

4. A species that is doing well in one part of Canada but has been eliminated from another region is classified as ______, while a species that is close to extinction in all parts of Canada is classified as _____.
A. extinct, vulnerable
B. threatened, endangered
C. extirpated, endangered
D. vulnerable, extinct

5. A group of organisms of the same species, located in the same area, is called a _____.
A. population
B. community
C. ecosystem
D. biome

6. Decomposers break down the nitrogen-containing chemicals in the wastes or body tissues (proteins) into
A. simpler chemicals such as ammonia (NH_3), then decomposing bacteria convert ammonia into nitrites and eventually to nitrates.
B. more complex chemicals such as ammonia (NH_3), then other decomposing bacteria convert ammonia into nitrates and eventually to nitrites.
C. simpler chemicals such as nitrites, then other decomposing bacteria convert nitrites into free nitrogen.
D. more complex chemicals such as nitrates, then other decomposing bacteria convert nitrates into free nitrogen.

7. In a bog you would expect
A. higher levels of usable nitrogen, since the denitrification process speeds up when the soil is acidic or becomes water-logged.
B. lower levels of usable nitrogen, since the nitrification process speeds up when the soil is acidic or becomes water-logged.
C. lower levels of methane, since methane-producing bacteria require anerobic conditions to grow, and bogs are high in oxygen.
D. low levels of carbon dioxide, since low levels of decomposing bacteria are found in bogs because of a lack of vegetation.

8. Predict what will happen if fertilizers are carried from the land to an aquatic ecosystem with spring runoff.
A. Algae populations will decrease, since nitrogen and phosphorus fertilizers inhibit all plant growth, including algae.
B. Algae populations will increase, since nitrogen and phosphorus fertilizers promote all plant growth, including algae.
C. Fish populations will increase, since increased plant growth will provide more carbon dioxide for fish.
D. Fish populations will be unaffected, since fish do not use nitrates found in fertilizers.

9. A step-by-step sequence showing how organisms feed on each other is referred to as
A. an ecosystem
B. a food chain
C. a population
D. an ecological pyramid

10. Agriculture is affecting ecosystems in Alberta because
A. wheat fields help cycle phosphates and nitrates in the soil.
B. crops in Alberta produce carbon dioxide, which contributes to global warming.
C. taiga soil is not fertile enough for wheat crops.
D. monoculture crops are replacing the biodiversity of prairie ecosystems.

11. An example of an endangered Canadian species is
A. passenger pigeon
B. whooping crane
C. elk
D. grizzly bear

12. Which of the following describes an abiotic factor in an ecosystem?
A. competition between species
B. predator–prey relationships
C. amount of sunlight
D. birth rate

Use the following information to answer questions 13 to 16.

Figure 1 shows a food chain.

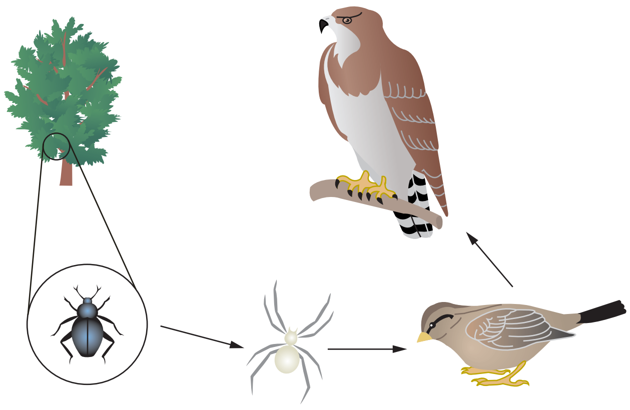

Figure 1

13. Which organism would be classified as the producer?
A. aspen tree
B. beetle
C. spider
D. sparrow

14. Which organism would be part of a population that would have the least biomass?
A. beetle
B. spider
C. sparrow
D. hawk

15. Based on your knowledge of number and biomass pyramids, which organism would you expect to have the greatest population?
A. aspen tree
B. beetle
C. spider
D. sparrow

16. Which level of organism has the least energy available to it?
A. beetle
B. spider
C. sparrow
D. hawk

Use the following information to answer questions 17 to 20.

The temperature of the air, the litter, the topsoil (10 cm below the surface), and the subsoil (30 cm below the surface) were monitored in one location in a temperate deciduous forest through the day. Use the data in **Figure 2** to answer questions 17 to 20.

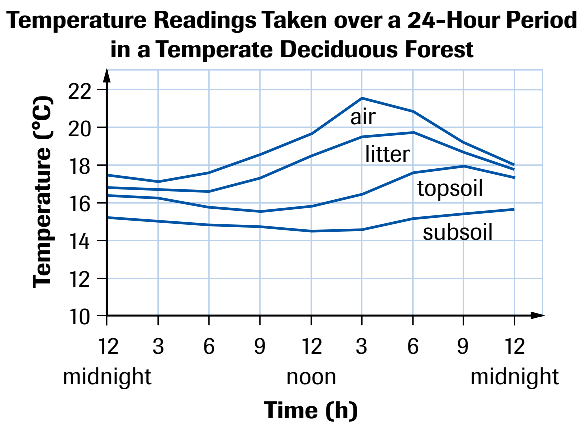

Figure 2

17. In which area of the forest did the greatest variation in temperature occur?
A. air
B. litter
C. topsoil
D. subsoil

18. Using a 24-h clock, at what time of day was the maximum ambient air temperature obtained?
A. 18:00
B. 3:00
C. 24:00
D. 15:00

19. What abiotic factor would account for the greatest difference in temperature readings in the litter?
A. wind
B. exposure to sunlight
C. moisture of the soil
D. thickness of the blanket of leaves

20. For the experiment described above, the dependent variable (responding variable) and independent variable (manipulated variable) are, respectively,
A. temperature and type of soil
B. type of soil and time
C. temperature and time
D. time and temperature

Part 2

21. Use the Great Slave Lake food web in **Figure 3** to **sketch** an ecological pyramid of numbers.

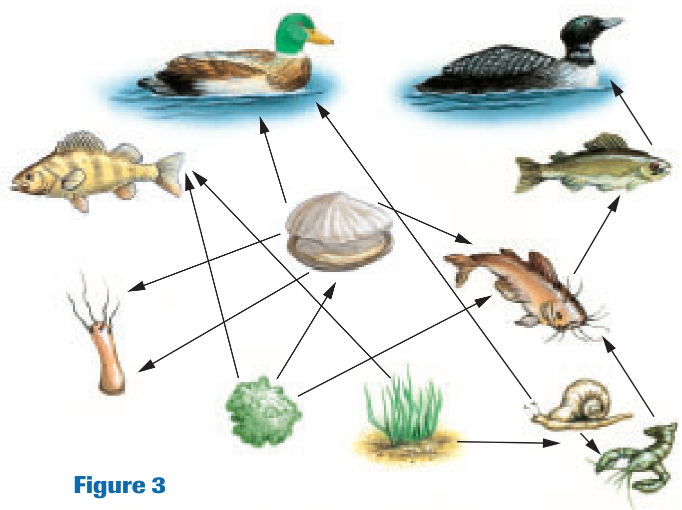

Figure 3

Use the following information to answer questions 22 to 27.

Two different experiments were carried out to determine the effects of different factors on photosynthesis. A freshwater plant, *Elodea*, was placed in a test tube of water. A light was placed at various distances from the plant for 5 min, then the number of oxygen bubbles produced by the plant were counted for 1 min. Different colours of light bulbs were used as well. The data are shown in **Table 1**.

22. DE **Identify** the two questions that the researcher is attempting to answer.

23. DE Write a hypothesis for both questions being investigated.

24. DE Represent the results of the experiment **graphically**.

25. DE **Identify** the two variables that affect the rate of photosynthesis.

26. DE **Why** are oxygen bubbles counted?

27. DE State the conclusions for the experiment.

28. DE The removal of a predator often has consequences that extend beyond the immediate food chain. In Bangladesh, where frog populations have been decimated to supply restaurants with delicacies, the number of mosquitoes has increased. In turn, this has caused a dramatic rise in cases of malaria among humans. Write a unified response addressing the following aspects of frog and mosquito populations in Bangladesh.

- **How** has the decline in frog populations affected human health?
- **Describe** a technological approach and an ecological approach for controlling malaria. **Describe** one advantage and one disadvantage for each approach.

29. The worldwide disappearance of frogs is a puzzle. In some areas, scientists don't really know what is causing the problem. **Illustrate** each of the following hypotheses regarding the causes of the disappearance of frogs with a supporting example. **Describe** things that the average citizen could do to remedy the problem implied by each hypothesis.

(a) Hypothesis: loss of habitat
(b) Hypothesis: decreasing quality of air and water
(c) Hypothesis: increase in ultraviolet radiation
(d) Hypothesis: climate change

30. There are a number of different reasons for extinction. Use Canadian examples to **illustrate** why extinction has occurred for each of the causes described below.

(a) the competition between naturally occurring species and exotic species introduced into the area
(b) the reduction of natural habitats
(c) climate change
(d) over-hunting

Use the following information to answer questions 31 to 33.

The water entering the ocean from the river in **Figure 4**, on the next page, is polluted with nitrates. A group of scientists decided to identify the sources of pollution. They chose five different testing sites to measure nitrate concentration in the water.

Table 1 Data from *Elodea* Experiment

Distance of light from test tube (cm)	Number of O_2 bubbles produced (1 min), white light bulb	Number of O_2 bubbles produced (1 min), red light bulb	Number of O_2 bubbles produced (1 min), green light bulb
5	25	10	4
10	20	8	2
15	15	6	1
20	10	4	0
25	5	2	0

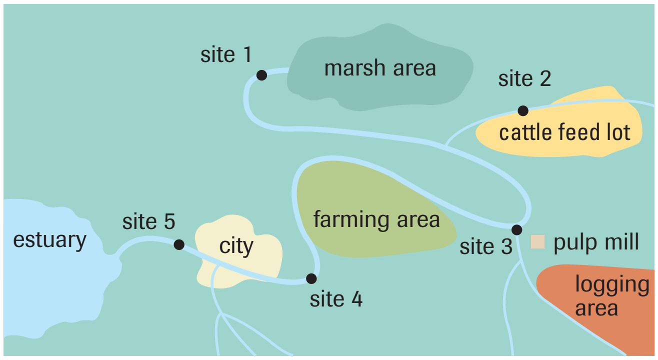

Figure 4

31. Choose two sites in **Figure 4** and **explain** why these two sites might show a local source of nitrates. DE

32. **Describe** two effects of severe nitrate pollution. DE

33. Choose one site in **Figure 4** and **describe** how the level of nitrates in the water could be reduced. DE

34. As the available natural wildlife habitats are reduced worldwide, scientists have expressed concerns about animals that occupy the highest trophic levels of energy pyramids. Using energy flow as an argument, **explain** why these animals would be most severely affected.

Use the following information to answer questions 35 to 37.

In 1965, NASA scientists compared the atmosphere of Earth with those of Mars and Venus. Their data are shown in **Table 2**.

Table 2 Chemical Composition of Venus, Earth, and Mars

Chemical composition	Venus	Earth	Mars
carbon dioxide	95 %	0.03 %	95 %
nitrogen	2 %	77 %	3 %
oxygen	none	21 %	none
chemical equilibrium	yes	no	yes

35. There are very high levels of carbon dioxide in the atmospheres of Mars and Venus. **How** might this affect the temperature of these planets? DE

36. Of these three planets, oxygen is only found in Earth's atmosphere. **Why** is this an important fact? DE

37. Suggest some reasons **why** Earth's atmosphere is not in equilibrium. DE

Use the following information to answer questions 38 to 42.

Figure 5 shows an apparatus that was used to measure water consumption by a plant.

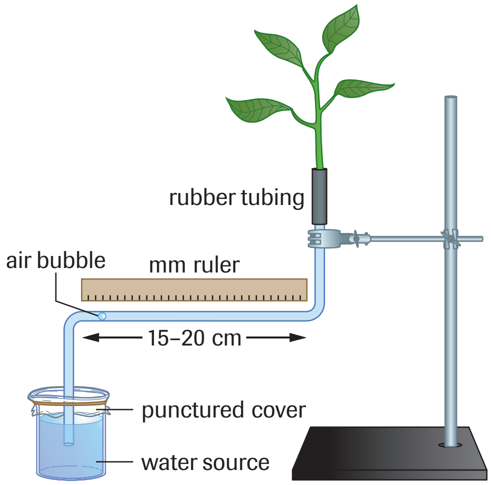

Figure 5

38. **Identify** the problem being investigated by this experiment. DE

39. **Identify** two variables that would affect water loss by transpiration. DE

40. **Sketch** a graph of the data provided in **Table 3**. DE

41. **Predict** how placing a plastic bag over the leaves would affect transpiration. DE

42. **Identify** two adaptations of the plant that reduce water loss by transpiration. DE

Table 3 Change in Mass of Plant Over Time

Time (min)	Mass of potometer + plant (g)	Change in mass of potometer + plant (g)
0	150.2	0
10	143.6	6.6
20	137.2	13.0
30	131.4	18.8
40	125.4	24.8

43. Review the focusing questions on page 2. Using the knowledge you have gained from this unit, briefly **outline** a response to each of these questions.